PB84-126689

Performance Audit Procedures for Opacity Monitors

Entropy Environmentalists, Inc.
Research Triangle Park, NC

Prepared for

Environmental Protection Agency
Research Triangle Park NC

Jan 83

U.S. Department of Commerce
National Technical Information Service
NTIS

PB84-126689

United States
Environmental Protection
Agency

Office of Air Quality
Planning and Standards
Research Triangle Park NC 27711

EPA-340/1-83-010
January 1983

Stationary Source Compliance Series

EPA

Performance Audit Procedures for Opacity Monitors

REPRODUCED BY
NATIONAL TECHNICAL
INFORMATION SERVICE
U.S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA. 22161

TECHNICAL REPORT DATA

(Please read Instructions on the reverse before completing)

1. REPORT NO. EPA-340/1-83/010	2.	3. RECIPIENT'S ACCESSION NO. PB84 126689
4. TITLE AND SUBTITLE Performance Audit Procedures for Opacity Monitors		5. REPORT DATE January 1983
		6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) Entropy Environmentalists, Inc.		8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS Entropy Environmentalists, Inc. P.O. Box 12291 Research Triangle Park, NC 27709		10. PROGRAM ELEMENT NO.
		11. CONTRACT/GRANT NO. 68-01-6317
12. SPONSORING AGENCY NAME AND ADDRESS OAQPS Stationary Source Compliance Division Waterside Mall, 401 M Street, SW Washington, DC 20460		13. TYPE OF REPORT AND PERIOD COVERED FINAL - IN-HOUSE
		14. SPONSORING AGENCY CODE EPA/200/04
15. SUPPLEMENTARY NOTES		

16. ABSTRACT

Field performance audit procedures were developed for five common opacity monitoring systems: (1) Lear Siegler, Inc. (LSI) Model RM41, (2) Dynatron, Inc. Model 1100, (3) Contraves Goerz Corporation Model 400, (4) Environmental Data Corporation (EDC) Model 1000A, and Thermo Electron Corporation Model D-R280 AV. These procedures were designed to enable audits to be performed by a single, relatively inexperienced technician. The results of the audit establish the overall quality of the reported opacity monitoring data and detect deficiencies within the source's operation and maintenance program which affect the accuracy and availability of the monitoring systems. This document contains monitor-specific audit procedures and data recovery calculation worksheets for use in conducting performance audits of installed opacity monitoring systems.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Air Pollution Monitoring	Opacity Monitoring Systems Audit Procedures	

18. DISTRIBUTION STATEMENT Release to Public	19. SECURITY CLASS *(This Report)* unclassified	21. NO. OF PAGES 174
	20. SECURITY CLASS *(This page)* unclassified	22. PRICE

EPA Form 2220-1 (Rev. 4-77) PREVIOUS EDITION IS OBSOLETE

EPA-340/1-83-010

Performance Audit Procedures for Opacity Monitors

Prepared by:

Entropy Environmentalists, Inc.
Research Triangle Park
North Carolina

Prepared for:

Darryl von Lehmden
and
Thomas Logan

Quality Assurance Division
United States Environmental Protection Agency
QAD Contract No. 68-02-3431

and

Louis R. Paley
Stationary Source Compliance Division

and

Anthony Wayne
Region VII

SSCD Contract No. 68-01-6317

U.S. ENVIRONMENTAL PROTECTION AGENCY
Office of Air Quality Planning and Standards
Stationary Source Compliance Division
Washington, D.C. 20460

January 1983

The Stationary Source Compliance series of reports is issued by the Office of Air Quality Planning and Standards, U.S Environmental Protection Agency, to assist Regional Offices in activities related to compliance with implementation plans, new source emission standards, and hazardous emission standards to be developed under the Clean Air Act. Copies of Stationary Source Compliance Reports are available - as supplies permit - from Library Services, U.S. Environmental Protection Agency, MD-35, Research Triangle Park, North Carolina 27711, or may be obtained, for a nominal cost, from the National Technical Information Service, 5285 Port Royal Road, Springfield, Virginia 22151.

This report has been reviewed by the Office of Air Quality Planning and Standards, U.S. Environmental Protection Agency, and approved for publication as received from Entropy Environmentalists, Inc. Approval does not signify that the contents necessarily reflect the views and policies of the U.S. Environmental Protection Agency, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

ABSTRACT

Field performance audit procedures were developed for five common opacity monitoring systems: (1) Lear Siegler, Inc. (LSI) Model RM41, (2) Dynatron, Inc. Model 1100, (3) Contraves Goerz Corporation Model 400, (4) Environmental Data Corporation (EDC) Model 1000A, and (5) Thermo Electron Corporation Model D-R280 AV. These procedures were designed to enable audits to be performed by a single, relatively inexperienced technician. The results of the audit establish the overall quality of the reported opacity monitoring data and detect deficiencies within the source's operation and maintenance program which affect the accuracy and availability of the monitoring system.

This document contains monitor-specific audit procedures and data recovery calculation worksheets for use in conducting performance audits of installed opacity monitoring systems.

TABLE OF CONTENTS

Section 1. Introduction. 1

1.1 Survey Data Collection 1
1.2 General Audit Procedures and Methodology 3

Section 2. Lear Siegler, Inc. Model RM41 Opacity Monitoring System 9

2.1 Stack Exit Opacity Determination 12
2.2 Monitoring System Check. 13
2.3 Calibration Check. 21
2.4 Performance Audit Data Retrieval 24
2.5 Analysis of Performance Audit Data 25

Section 3. Dynatron, Inc. Model 1100 Opacity Monitoring System 29

3.1 Stack Exit Opacity Determination 32
3.2 Monitoring System Check. 33
3.3 Calibration Check. 36
3.4 Performance Audit Data Retrieval 38
3.5 Analysis of Performance Audit Data 39

Section 4. Contraves Goerz Corporation Model 400 Opacity Monitoring System. 41

4.1 Stack Exit Opacity Determination 44
4.2 Monitoring System Check. 45
4.3 Calibration Check. 50
4.4 Performance Audit Data Retrieval 52
4.5 Analysis of Performance Audit Data 53

Section 5. Environmental Data Corporation Model 1000A Opacity Monitoring System. 57

5.1 Stack Exit Opacity Determination 57
5.2 Monitoring System Check. 58
5.3 Calibration Check. 60
5.4 Performance Audit Data Retrieval 62
5.5 Analysis of Performance Audit Data 63

Section 6. Thermo Electron Corporation Environmental Data D-R280 AV Opacity Monitoring System 65

6.1 Stack Exit Opacity Determination 65
6.2 Monitoring System Check. 68
6.3 Calibration Check. 74
6.4 Performance Audit Data Retrieval 76
6.5 Analysis of Performance Audit Data 77

Table of Contents
(continued)

Appendices. 81

- Appendix A. General Transmissometer Audit Questionnaire
- Appendix B. Lear Siegler RM41 Performance Audit Data Sheets
- Appendix C. Dynatron 1100 Performance Audit Data Sheets
- Appendix D. Contraves 400 Performance Audit Data Sheets
- Appendix E. EDC 1000A Performance Audit Data Sheets
- Appendix F. Thermo Electron D-R280 AV Performance Data Sheets

1. INTRODUCTION

In 1975, the Environmental Protection Agency (EPA) promulgated specific provisions for several source categories subject to Standards of Performance for New Stationary Sources that required continuous monitoring of effluent opacity. EPA also promulgated similar provisions that required revisions of State Implementation Plans to include opacity monitoring requirements for selected source categories. Pursuant to these provisions, State and Federal air pollution control agencies require source owner/operators to evaluate the performance of installed opacity monitors, while this initial performance specification test (PST) serves to verify that opacity monitors are properly installed and capable of providing reliable data, subsequent performance audits conducted by the control agency provide independent means for evaluating (1) the accuracy of monitoring data reported to the agency, and (2) the adequacy of monitor operation and maintenance procedures utilized by the affected source. The audit results allow control agencies to place greater reliance on opacity monitoring data to provide indications of: (1) the degree of compliance with Federal and State opacity standards, (2) the particulate emission levels, (3) the process and pollution control equipment operation and maintenance, and (4) the need for control agency inspection of the source.

The performance audit procedures presented in this document are based on a thorough review of the manufacturers' instrument operating manuals, as well as extensive testing of "portable" opacity monitors and other field audit devices supplied by the Quality Assurance Division of the EPA. While these procedures do cover a broad range of monitor performance and site operating and maintenance criteria, they are not all-inclusive, because a technically rigorous analysis of monitor electronic systems would require a high level of competence and familiarity on the part of audit personnel. Rather, these procedures have been developed with the goal of simplifying the technical aspects of performance audits so that the audits can be conducted by a single, relatively inexperienced person.

1.1 SURVEY DATA COLLECTION

This section describes the procedures employed in the gathering of source and monitor data prior to the actual field audit. Both the plant information survey and the on-site survey are discussed. Examples of the data sheets to be used in these surveys are contained in Appendix A of this document.

1.1.1 Plant Information Survey

The plant information survey serves to collect data about the source and monitor that is necessary to plan the field audit test. This information can be gathered in a telephone contact with a site representative, or, in instances where time is not a crucial factor, the questionnaire can be mailed to the source for completion. In general, the plant information survey collects data in the following three areas.

> Site Identification/Location/Description. This information identifies and describes the source. In most cases, the source name is a corporation, and the site is identified as a particular plant or unit. The plant contact is an individual representing the source who has some knowledge of the site and the control device/monitoring

system, and who is responsible for providing information and coordinating the audit program. The individual facilities employing opacity monitors are delineated, along with descriptions as to their outputs (typically in electric power or steam), control devices (precipitators, baghouses, scrubbers, flue gas desulfurizers, etc.), and the type of fuel.

Opacity Monitor Identification/Background. Each monitor to be audited is described with reference to the manufacturer, model number, and serial number. The installation date and the date of certification (i.e., Performance Specification Test) provide information as to whether the installation, operation, and maintenance of the monitor has been evaluated in accordance with EPA standards. A delay of more than 6 months between installation and certification could be indicative of problems that have not been resolved.

Opacity Monitor Location. These questions relate to the location/accessibility of the opacity monitor and the monitor control panel. Because the audit procedures require access to both of these units, the mode of access is critical to the planning of the audit. The height of the opacity monitor location and the type of access (stairs, ladder, elevator, etc.) will dictate the safety measures required and the types of ancillary equipment needed for the audit program. The location and mounting of the monitor control unit also affects the type of equipment required for the audit, and may adversely affect the collection of data if access to the monitor's internal circuits is limited or hindered. Finally, the type of monitor enclosure gives an advance indication of the physical condition of the transceiver with respect to dust and moisture accumulation.

1.1.2 On-Site Survey

The on-site survey provides specific information about the monitor location, operation, and maintenance that is useful in conducting the audit and in reporting the history of the monitor. Information gathered in the on-site survey can be classified under the three following general areas:

Monitor Location. Detailed information is required to verify that the monitor is accessible for routine maintenance and calibration. The monitor must be installed so that it is free from vibration and so that it is not near any flow disturbances, such as bends or restrictions in the duct or stack. Typically, the monitor location is specified in units of duct diameters from the nearest flow disturbance.

Operation/Calibration. Information about the data recording system is required to determine the time interval for each measurement, based on whether the monitor provides instantaneous readings or averaged readings over some integration period. It is also necessary to determine whether the chart readings have been corrected for stack exit conditions (see the discussion of the Stack Exit Correlation Error, Section III). Extensive information on monitor calibration frequency, procedures, and conditions is required to determine the adequacy of available historic data and to evaluate the site's operating and maintenance (O&M) procedures.

Maintenance History. The monitor's operational history for the 30 days preceding the audit is evaluated. Available logbooks are examined, and notations are made of significant scheduled and unscheduled maintenance. Data logs are evaluated to correlate monitor down-times with maintenance records, and notations are made as to whether routine maintenance is conducted by source personnel, by the monitor vendor, or by an outside maintenance consultant. In addition, the inventory of monitoring system spare parts is evaluated, and important parts that are readily available are listed. Finally, monitoring system components with histories of repeated failure are listed in order to provide an indication of the reliability of system components and the frequency of unscheduled maintenance.

1.2 GENERAL AUDIT PROCEDURES AND METHODOLOGY

Within this section, the audit methodology is discussed generally, and the criteria used in the evaluation of monitor performance are delineated. Specific field audit procedures for five commonly encountered models of opacity monitors are described in Sections 2 - 6, which follow. The monitor-specific procedures are presented in such a way as to facilitate ease in field use.

1.2.1 Field Audit Program Description

The opacity monitor audit program was designed to provide accurate, reliable analyses of monitor performance through a simple, quick field test procedure which can be performed by a single technician with a basic understanding of monitor operation. Equipment necessary for a typical audit includes a specialized retroreflector for the specific monitor being tested; this is used to simulate clear stack conditions. In addition, three neutral density filters, traceable to the National Bureau of Standards (NBS), are necessary to evaluate both the linearity and the calibration error of the monitor. All of the equipment required for an opacity monitor performance audit can be transported in a small suitcase.

The field audit procedures are used to determine whether the monitor has been properly operated and whether the monitor accuracy and calibration are of sufficient quality to provide useful opacity data. Although these procedures may differ slightly in their order for each type of monitor, they all include the following three basic analyses:

(1) Monitor Component Analysis

- The stack exit diameter and monitor pathlength are determined to verify the accuracy of the monitor's preset stack exit opacity correction factor.

- The fault lamp indicators on the monitor's control panel are checked to determine whether the monitor is operating within the manufacturer's prescribed limits.

- Various internal electronic checks are performed using the controls in the monitor's control unit to further verify the operational status of the monitor.

- The control panel meter and chart recorder responses are compared to the monitor's internal span value in order to determine the accuracy of the control panel meter and the internal zero and span functions.

(2) Monitor Maintenance Analysis

- The optical alignment and dust accumulation on optical surfaces are checked to determine the adequacy of the monitor mounting and maintenance frequency.

(3) Calibration Error Analysis

- The calibration error and linearity of the monitor are checked using neutral density filters.

1.2.2 Audit Procedures

Each opacity monitor field audit comprises up to 10 specific analyses which encompass the monitor's accuracy, linearity, and the quality of monitor operation and maintenance practices. The audit procedures are organized sequentially according to the location of the monitoring system components (moving from the control unit location to that of the opacity monitor and then back to the control unit), so that a single individual can conduct the audit. The audit procedures and their associated criteria are detailed as follows:

Fault Lamp Status. The control unit of a typical opacity monitor has several fault lamps that warn of monitor system malfunctions and/or impending conditions of excessive opacity. These fault lamps are indicative of a variety of conditions, depending on the manufacturer, but most units use fault lamps to monitor the intensity of the optical beam, the quantity of dust on monitor optical surfaces, the status of internal circuitry that maintains monitor calibration, and the magnitude and rate of increase of opacity. In general, the monitor parameter indicated by a fault lamp is "out of specification" if the fault lamp is illuminated. However, this does not account for faults in the lamp circuitry or for a burned-out or missing lamp bulb.

Automatic Gain Control (AGC) Circuit Analysis. Lear Siegler opacity monitors employ an AGC circuit to compensate electronically for reductions in the optical beam intensity resulting from power supply fluctuations or normal bulb deterioration. This compensation maintains beam intensity, and thus reference signal values at a constant level within the manufacturer's specified range. A fault condition exists when a Lear Siegler monitor's AGC circuit is not functional, and such a condition is indicated when the AGC lamp is not lit. However, an AGC circuit fault does not necessarily diminish the accuracy of opacity measurements, provided that the reference signal value is within the specified range.

Stack Exit Correlation Analysis. Typically, the cross-stack optical pathlength of the installed opacity monitor is not equal to the diameter of the stack exit. To obtain a true stack exit opacity value, the measured opacity at the monitor location is corrected to stack exit conditions through the use of a pathlength correction factor. The stack exit correlation error is the percent error of the pathlength correction factor, as preset by the manufacturer, relative to a pathlength correction factor calculated through the use of actual measurements, blueprints, etc. This stack exit correction factor should not exceed ±2 percent.

Control Panel Meter Analysis. Most opacity monitors have a panel meter located on their control or transceiver units to monitor opacity readings or to adjust an internal monitor parameter. The control panel meter correction factors are the ratios of control panel meter readings to the specified internal values for either the opacity filter, input signal, or the optical density. The panel meter is "out of specification" if the panel meter correction factor exceeds ±2 percent (outside the 0.98 to 1.02 range).

Reference Signal Error. The Lear Siegler monitor reference signal is an internal monitor electrical signal output that indicates the electronic alignment of the transceiver circuitry (usually 20 ma). The reference signal analysis serves as an internal verification of the beam intensity as well as an indication of the status of the photo detector and its associated electronics. The reference signal is considered to be "out of specification" when it varies by more than ±10 percent beyond the value specified by the monitor manufacturer.

Internal Zero and Span Analysis. The internal zero and span analysis evaluates the monitor's ability to maintain calibration by automatically adjusting its internal electronics to compensate for dust accumulation on monitor optics. The zero and span errors are the percent opacity difference between the rated opacity values of the internal zero and span filters and those displayed on the control unit chart recorder. The zero and span errors are considered to be "out of specification" when either of them exceeds ±2 percent opacity.

Zero Compensation Analysis. The zero compensation circuit automatically adjusts the monitor's zero to compensate for dust accumulation on the transceiver's optical surfaces. This analysis is based on recording the zero compensation before and after cleaning the transceiver and retroreflector optical surfaces. The zero compensation is considered to be "out of specification" if the indicated value exceeds ±0.018 optical density (±4 percent opacity).

Monitor Alignment Analysis. The optical alignment of the transceiver/retroreflector system is critical in maintaining accurate opacity measurements. Misalignment of the beam can cause erroneously high opacity readings, because a significant portion of the measurement beam is not returned to the transceiver. Most opacity monitor manufacturers include provisions for an optical alignment check, either as a standard feature or as an option. Monitor alignment errors are indicated by an off-center beam path.

Optical Surface Dust Accumulation Analysis. The optical surface dust accumulation analysis determines the amount of dust (measured in terms of percent opacity) found on the optical surfaces, based on the reduction in opacity before and after cleaning of the optical surfaces. To obtain a reliable assessment, this audit analysis should be performed when the stack opacity is relatively constant. The optical surface dust accumulation is "out of specification" when the reduction in apparent opacity following optical surface cleaning exceeds 4 percent opacity.

Calibration Error Analysis. The calibration error analysis involves comparison of the monitor responses to the known opacity values for three reference neutral density filters (as modified in opacity value by the optical pathlength correction factor). The calibration of the reference filters used in this analysis is traceable to the NBS. This analysis indicates both the accuracy and the linearity of the monitor, and the monitor calibration is considered to be "out of specification" if the measured opacities vary from the reference filter rated values by more than 3 percent. The linearity of the monitor is indicated by the differences in monitor accuracy between the low, mid, and high calibration ranges.

1.2.3 Audit Limitations and Considerations

In general, the audit procedures contained herein are straightforward and simple, requiring only limited technical background from audit personnel. There are, however, several specific considerations which should be kept in mind in the course of implementing such a program.

- While these procedures were designed to enable a person with minimal experience in monitor operation to conduct the audit, audit personnel must receive some hands-on training, preferably during an audit, before attempting to conduct an audit without supervision.

- No monitor adjustments are to be made by the auditor except for those stated within the audit procedures.

- The opacity monitor pathlength determination can be confusing. The pathlength is computed using the inside diameter of the duct-work or stack, not the flange-to-flange dimension. Even though the transceiver and retroreflector exposed optics are beyond the inside stack/duct walls, the volume present between the optics and the inside wall of the exhaust system is filled with clean air from the air purge system. Therefore, attenuation of the opacity monitor measurement beam (due to particles transported within the effluent gas stream) will occur over the distance bounded by the inside stack/duct walls.

- The stack exit diameter refers to the inside diameter of the stack at its highest point where the effluent stream exits to the atmosphere.
- The audited system's strip charts should be marked to identify each point used as a datum for the audit. The time, date, and auditor's name should be indicated on the strip chart.
- Throughout the monitor-specific procedures, there are statements instructing the auditor to wait for a specified time interval. These waiting intervals are necessary to ensure that the monitoring system has had enough time to collect, process, and record the information desired. These waiting periods can be reduced somewhat by having two persons conduct the audit.
- When the dust accumulation analysis is performed, caution should be exercised to ensure that changes in effluent opacity are not mistaken for dust on the optical surfaces. This analysis should not be performed if the stack opacity is changing rapidly.
- If a source is off-line, clear stack conditions are not necessarily assured. Welding or other repair activities may disperse smoke or dust from the walls of the duct or stack. If hatches are left open, natural drafting may occur, again entraining any dust that may be deposited in the duct-work. Rain falling down the stack might also negate clear stack conditions.
- Care must be exercised when handling the neutral density filters utilized in the calibration error determinations. Any contamination, such as fingerprints or dust, can cause positive biases in the audit results. If any visible foreign matter is present on the audit filters, the filters should be cleaned using lens paper and lens cleaner. The filters should be rechecked before each use to ensure that no foreign matter has accumulated in the interim.

2. LEAR SIEGLER, INC., MODEL RM41

OPACITY MONITORING SYSTEM

The RM41 transmissometer system consists of three major components: the transmissometer, the air-purging and shutter system, and the remote control and data acquisition equipment. The transmissometer component consists of an optical transmitter/receiver (transceiver) unit mounted on one side of a stack or duct and a retroreflector unit mounted on the opposite side. The transceiver unit contains a light source, a photodiode detector, and their associated mechanical and electronic components; its output is transmitted to the control unit, which indicates optical density and stack exit opacity.

Figure 2-1 illustrates the general arrangement of the transceiver and retroreflector units on the stack, and provides further details of the chopped, dual-beam (i.e., the reference beam and the measurement beam) measurement technique utilized by the transceiver's optical system. The reference beam signal is monitored continuously by the automatic gain control (AGC) circuit, which compensates for signal perturbations (changes in lamp intensity) so that the reference signal remains constant. Since the AGC circuit affects both the reference signal and the measurement signal amplitude equally, lamp intensity changes are theoretically eliminated from the measurement signal.

The air-purging system serves a threefold purpose: (1) it provides an air window to keep exposed optical surfaces clean; (2) it protects the optical surfaces from condensation of stack gas moisture; and (3) it minimizes thermal conduction from the stack to the instrument. A standard installation has one air-purging system for the transceiver unit and one for the retroreflector unit; each system has a blower providing filtered air.

The shutters (optional) automatically provide protection for the exposed optical surfaces from smoke, dust, and stack gas whenever the purge airflow decreases below a predetermined rate. The shutters are activated by airflow sensors installed in the connecting hoses between the air-purging blower and the instrument units. Under most stack conditions, the shutters are reset automatically upon restoration of power to the blowers, but may have to be reset manually under high negative or high positive stack pressure conditions.

The control unit (Figure 2-2) converts the double-pass transmittance output from the transceiver, in conjunction with the reference amplitude output, to linear opacity and optical density measurements. It also corrects the opacity measurement according to the ratio of the stack exit diameter to the transmissometer pathlength, commonly referred to as the optical pathlength ratio (OPLR) by Lear Siegler. (The Model 611 unit is the most commonly used controller; however, an RM4100 microprocessor-based digital readout control unit is also available.)

Preceding page blank

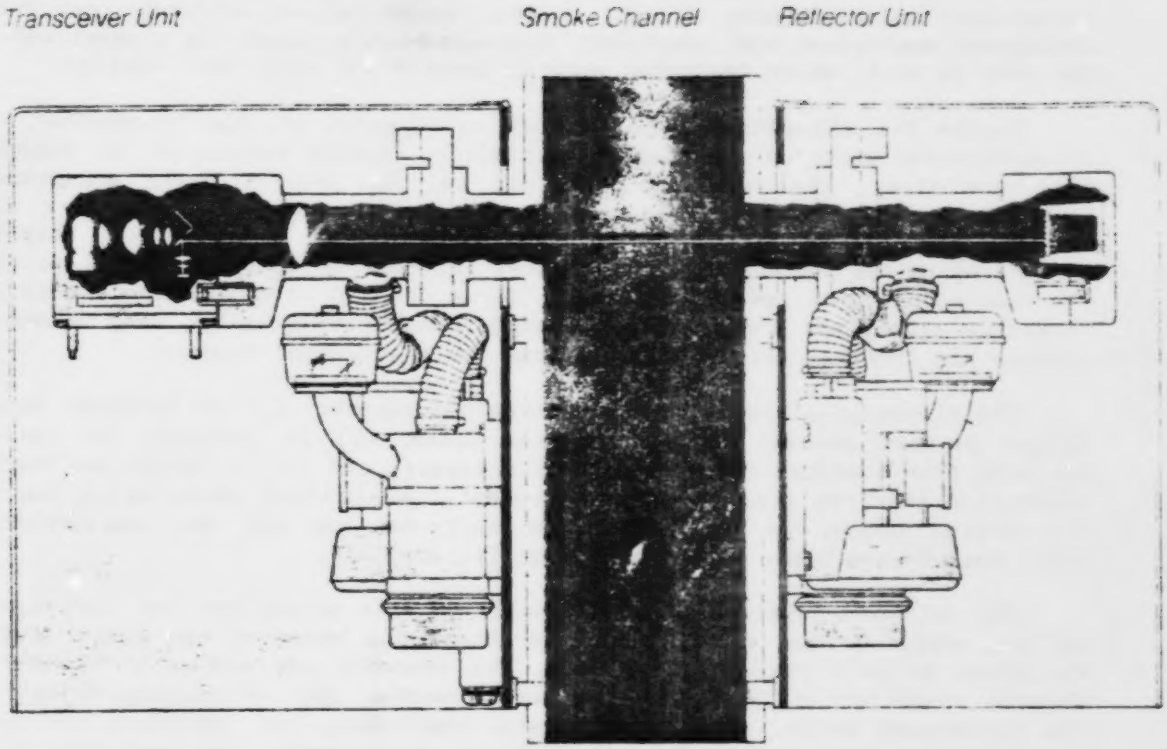

Transceiver Unit
Smoke Channel
Reflector Unit

Figure 2-1. Lear Siegler RM41
General Arrangement

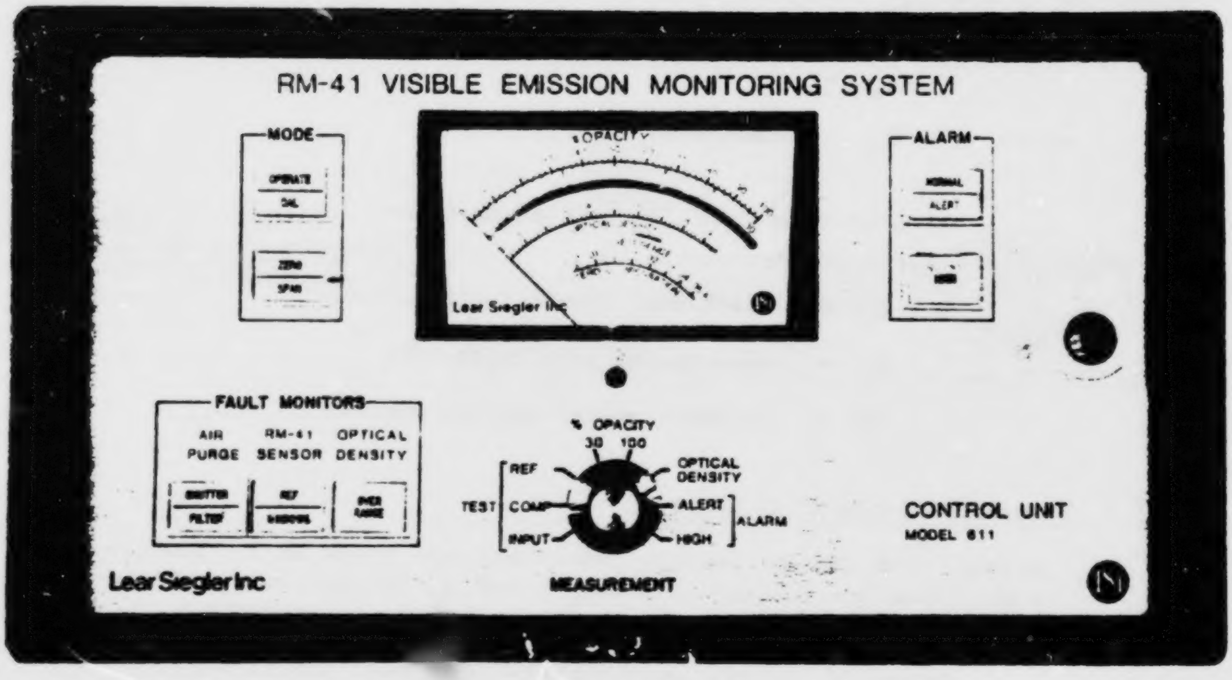

RM-41 VISIBLE EMISSION MONITORING SYSTEM
MODE
OPERATE
CAL
ZERO
SPAN
% OPACITY
Lear Siegler Inc
ALARM
NORMAL
ALERT
FAULT MONITORS
AIR PURGE
RM-41 SENSOR
OPTICAL DENSITY
SHUTTER
FILTER
REF
WINDOWS
OVER RANGE
% OPACITY
30
100
REF
TEST
COMP
INPUT
OPTICAL DENSITY
ALERT
HIGH
ALARM
MEASUREMENT
CONTROL UNIT
MODEL 611
Lear Siegler Inc

Figure 2-2. Lear Siegler RM41 Control Unit

2.1 STACK EXIT OPACITY DETERMINATION

The opacity monitor measures the amount of light transmitted across the stack and returned from the retroreflector. The control unit uses this information to calculate the optical density of the effluent stream at the monitor location. The optical density measurements are corrected for pathlength differences between the measurement site and the stack exit and are converted to opacity. The relationship between stack exit opacity and optical density is described by the following equation:

$$Op_x = 1 - 10^{-(OPLR)(OD)}$$

where: OP_x = stack exit opacity (%)

$OPLR = \frac{L_x}{L_t}$; optical pathlength ratio

L_x = stack exit diameter (ft)

L_t = measurement pathlength (ft)

OD = transmissometer optical density

2.1.1 Stack Exit Correlation Error

1. Measure the transmissometer pathlength and stack exit diameter and record the values on blanks 1 and 2, respectively, of the Lear Siegler RM41 Performance Audit Data Sheet in Appendix B.

   Note: If actual measurements are not practical, obtain the data from detailed plant blueprints or other available source information. The monitor pathlength is two times the length of the inside diameter of the stack at the monitor installation location.

2. Calculate the OPLR, (divide the value on blank 1 by the value on blank 2), and record the value on blank 3.

3. Record the preset OPLR value on blank 4.

   Note: The OPLR is preset by the manufacturer using information supplied by the source. While this preset ratio should be recorded on the first page of the monitor operation manual, it may have to be obtained from another source; in any case, the origin of this information should be noted.

2.2 MONITORING SYSTEM CHECK

This section describes checks to gather pertinent operating parameters necessary to ascertain whether the monitoring system is functioning properly. The control unit parameters are addresssed within the procedures found in Sections 2.2.1 through 2.2.6; tests for these parameters are performed at the RM41 contol unit location. The test procedures described in Sections 2.2.7 through 2.2.12 are performed at the transmissometer location to determine the status of the optical surfaces and the transmissometer alignment.

Many of the procedures call for a waiting period at the conclusion of an audit step to ensure that the strip chart recorder has had sufficient time to stabilize and record a steady response. For recorders with instantaneous opacity readings, a waiting interval of three minutes should be sufficient. For recorder displaying six-minute averages, a waiting period of thirteen minutes is recommended. At a later time during the audit, the auditor retrieves the recorded opacity data corresponding to the specific audit steps.

Although the audit can be conducted by one person, a second person can significantly reduce the waiting intervals and audit time. The second person can save time by staying with the strip chart recorder and recording the necessary data as soon as a steady reading occurs.

2.2.1 Fault Indicators Check

The following list describes the fault lamps that are found on the Lear Siegler control unit panel. Unless otherwise noted, the audit analysis can continue with illuminated fault lamps, provided that the source has been informed of the fault conditions.

4. Record the status (ON or OFF) of the FILTER fault lamp on blank 5.

   Note: An illuminated FILTER fault lamp indicates that the purge air blower may not be working properly or the filter element cleaning the purge air is dirty and is restricting the airflow. This fault lamp is not an indicator of dirt on the measurement window.

5. Record the status (ON or OFF) of the SHUTTER fault lamp on blank 6.

   Note: An illuminated SHUTTER fault lamp indicates that no measurement of stack opacity is being made since the shutter is blocking the optical path. The performance audit can continue, but the shutter fault condition precludes performance of audit analyses relating to the retroreflector and transceiver window checks.

6. Record the status (ON or OFF) of the REF fault lamp on blank 7.

   Note: An illuminated REF fault lamp indicates a reference signal decrease which may be due either to a fault in the automatic gain control (AGC) circuit or to a fault in the associated transceiver electronics (e.g., low line voltage, burned-out or improperly installed lamp, etc.).

7. Record the status (ON or OFF) of the WINDOW fault lamp on blank 8.

   Note: An illuminated WINDOW fault lamp indicates that the control unit automatic zero compensation exceeds the maximum preset limit. The zero compensation circuit electronically corrects the monitor's opacity responses for dust accumulation on the transceiver measurement window. An excessive zero compensation limit may bias the opacity data; zero and span calibrations will also be biased by the same amount, permitting measurement of the amount of uncorrected zero drift.

8. Record the status (ON of OFF) of the OVER RANGE fault lamp on blank 9.

   Note: An illuminated OVER RANGE fault lamp indicates that the optical density of the effluent exceeds the range selected on the optical density circuit board. This problem affects the recording of the opacity data. If this fault lamp remains illuminated for an extended period of time, switch to a higher optical density range (note the original range before changing) on the "optical density" circuit board located in the control unit (see Figure 2-3).

2.2.2 Reference Signal Check

9. Mark the time and date on the opacity chart recorder.

10. Record the original position on blank 10 of the MEASUREMENT knob on the control unit panel.

11. Turn the MEASUREMENT knob to the REF position.

12. Record the current value on blank 11 that is displayed on the 0-30 scale on the control panel meter.

    Note: The reference signal should be within the green area marked "Reference."

2.2.3 Check Opacity Measurement Range

13. Turn the MEASUREMENT knob to the 100% OPACITY position.

14. Locate the "opacity" circuit board inside the control unit (the fourth card from the left).

    Note: There is a five position switch (S1 on "opacity" board shown in Figure 2-3) on the circuit board.

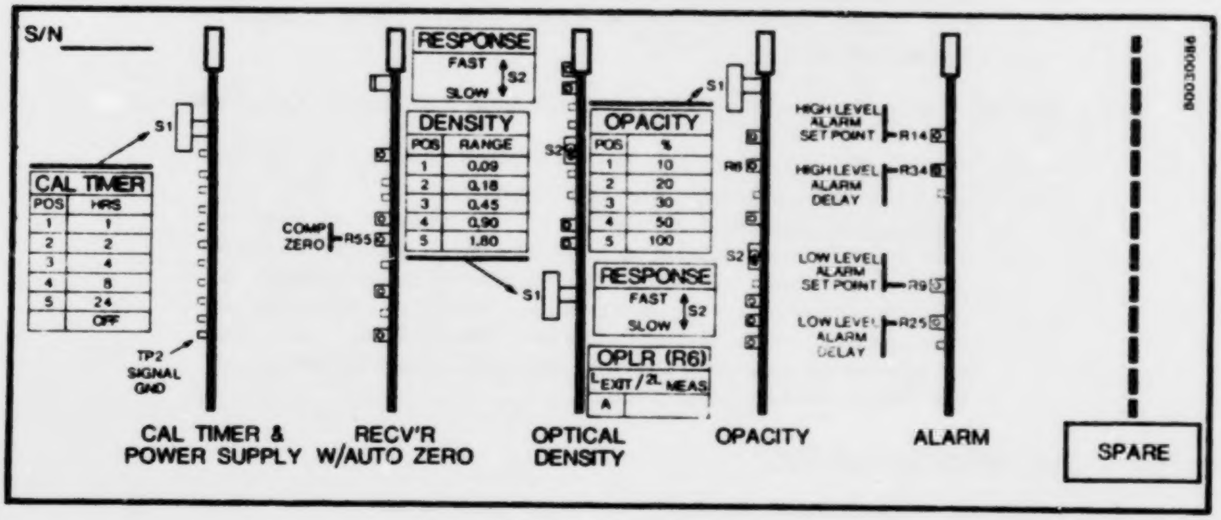

S/N
S1
CAL TIMER
POS HRS
1 1
2 2
3 4
4 8
5 24
OFF
TP2
SIGNAL
GND
CAL TIMER &
POWER SUPPLY
RESPONSE
FAST
SLOW
S2
DENSITY
POS RANGE
1 0.09
2 0.18
3 0.45
4 0.90
5 1.80
COMP
ZERO
R55
S1
RECV'R
W/AUTO ZERO
S2
OPACITY
POS %
1 10
2 20
3 30
4 50
5 100
RESPONSE
FAST
SLOW
S2
OPLR (R6)
L EXIT / 2L MEAS
A
OPTICAL
DENSITY
S1
R6
S2
OPACITY
HIGH LEVEL
ALARM
SET POINT
R14
HIGH LEVEL
ALARM
DELAY
R34
LOW LEVEL
ALARM
SET POINT
R9
LOW LEVEL
ALARM
DELAY
R25
ALARM
SPARE
80030086

Figure 2-3. Lear Siegler RM41 Control Unit Circuit Board Arrangement

15. Record the position of the S1 switch on blank 12.

16. Rotate the S1 switch to the fifth position.

Note: This adjustment will expand the control unit output to a 0 to 100% opacity range which is necessary for subsequent audit analyses.

2.2.4 Instrument Zero Check

17. Press the $\frac{\text{OPERATE}}{\text{CAL}}$ button on the control panel to initiate the zero mode.

Note: The green OPERATE light should go out when the zero check retroreflector is in place. The yellow CAL light and the green ZERO light should remain illuminated.

18. Record the value on blank 13 displayed on the chart recorder.

Note: The cross-stack zero is simulated by using the zero retroreflector in the transceiver. The zero check provides an indication of the amount of dust on the measurement window and on the zero retroreflector and/or of the status of the electronic alignment of the instrument. It does not, however, provide an indication of dirty window conditions at the measurement retroreflector, optical misalignment, or the true cross-stack zero.

2.2.5 Zero Compensation Check

19. Turn the MEASUREMENT knob to the COMP position.

20. Record the zero compensation optical density value (blank 14) displayed on the bottom scale of the control panel meter.

Note: The monitor's lamp output is split into two beams: (1) the reference beam, which produces the reference signal within the monitor (see Section 2.2.2), and (2) the measurement beam, which passes through the off stack effluent. When the zero retroreflector is positioned in front of the measurement beam, the measurement beam passes only through the transceiver's measurement window before travelling back into the monitor. The signal produced by the measurement beam is compared with the signal from the reference beam; the difference between the two signals is due to the attenuation of the measurement beam by the transceiver measurement window. The monitor automatically compensates for this measured difference. The zero compensation value displayed on the panel meter indicates the difference in terms of optical density (OD).

2.2.6 Internal Span Check

21. Locate the "optical density" circuit board inside the control unit.

    Note: This circuit board is the third board from the left. There is a five position switch (S1 on "optical density" board shown in Figure 2-3) on the circuit board.

22. Record the initial position of the S1 switch on blank 15.

23. Rotate the S1 switch to the fifth position, if necessary.

24. Turn the MEASUREMENT knob to the 100% OPACITY position.

25. Press the $\frac{\text{ZERO}}{\text{SPAN}}$ button to initiate the span mode.

26. Record the span value on blank 16 that is displayed on the control panel meter (0-100% Op scale) and record the span value displayed on the chart recorder on blank 17.

27. Turn the MEASUREMENT knob to the INPUT position.

28. Record the control panel meter value on blank 18 that is displayed on the 0-30 scale.

29. Turn the MEASUREMENT knob to the OPTICAL DENSITY position.

30. Record the control panel meter reading on blank 19 that is displayed on the 0-9 OD scale.

31. Return the MEASUREMENT knob to the 100% OPACITY position.

    Note: The span is accomplished by the transceiver: a neutral density filter is automatically inserted into the measurement beam while the zero retroreflector is in place. The span measurement provides another check of the electrical alignment and the linearity of the transmissometer response to opacity.

32. Press the $\frac{\text{OPERATE}}{\text{CAL}}$ button to return the monitor to the stack opacity measurement mode.

    Note: The OPERATE and CAL lamps will light to indicate movement of the zero retroreflector. The $\frac{\text{OPERATE}}{\text{CAL}}$ button should not be pressed when both the OPERATE and CAL lights are illuminated.

2.2.7 Span Filter Check

33. Record the span filter's optical density value on blank 20 and the output current value on blank 21.

> Note: These values are displayed on the bottom of the transceiver, on the serial number label (Figure 2-4). However, the current span filter values may not correspond to the information displayed on the serial number label; the span filter may have been changed, or new values may have been assigned to the span filter during previous monitor calibration. In any case, current span filter values should be verified and recorded.

34. Mark the time of the day on the chart recorder.

2.2.8 Automatic Gain Control Check

35. Determine whether the green light (AGC LED, Figure 2-4) on the transceiver is illuminated, and record light status (ON or OFF) on blank 22.

2.2.9 Alignment Check

36. Remove the protective cover on the transceiver mode knob located on the bottom right-hand side of the transceiver (see Figure 2-4).

37. Turn the knob until ALIGN can be seen through the knob window.

38. Determine the monitor alignment by looking through the bull's eye (Figure 2-4) and observing whether the image is in the circular target.

39. Record whether the image is inside the circular target (YES or NO) on blank 23.

> Note: Instrument optical alignment has no effect on the internal checks of the instrument or on the calibration check using the audit device; however, if the optical alignment is not correct, the stack opacity data will be biased high, since all the light transmitted to the retroreflector is not returned to the detector.

40. Return the transceiver mode knob to OPERATE (in the knob window) to resume measurement of the stack effluent and replace the mode knob's protective cover.

2.2.10 Retroreflector Window Check

41. Allow the monitor to operate at least three minutes (thirteen minutes if the monitoring system processes the data through a six-minute averaging circuit).

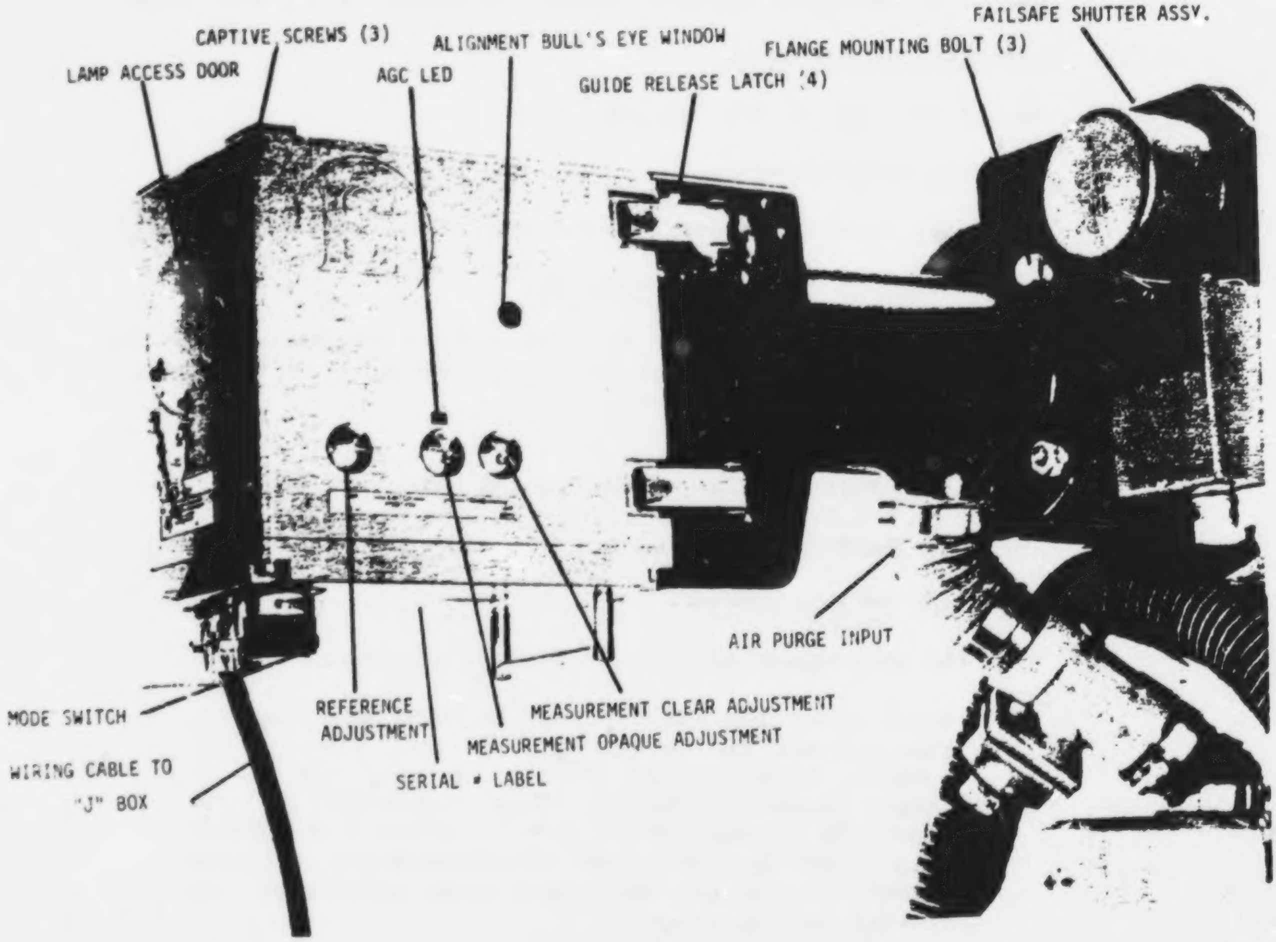

FAILSAFE SHUTTER ASSY.
CAPTIVE SCREWS (3)
ALIGNMENT BULL'S EYE WINDOW
FLANGE MOUNTING BOLT (3)
LAMP ACCESS DOOR
AGC LED
GUIDE RELEASE LATCH (4)
AIR PURGE INPUT
MODE SWITCH
REFERENCE ADJUSTMENT
MEASUREMENT CLEAR ADJUSTMENT
MEASUREMENT OPAQUE ADJUSTMENT
WIRING CABLE TO "J" BOX
SERIAL # LABEL

Figure 2-4. Lear Siegler RM41 Transceiver

42. Clean the window of the measurement retroreflector.

43. Record the time of the measurement retroreflector window cleaning on blank 24.

44. Wait an additional three or thirteen minutes (depending upon the use of an averaging circuit) before proceeding to the next step.

2.2.11 Tranceiver Window Check

45. Record the time of day on blank 25.

46. Open the transceiver head.

47. Clean the transceiver and zero retroreflector optical surfaces.

48. Record time of cleaning on blank 26.

49. Wait an additional three or thirteen minutes (depending upon the use of an averaging circuit) before proceeding to the next step.

2.2.12 Reset Zero Compensation

50. Press the $\frac{\text{OPERATE}}{\text{CAL}}$ button on the control unit.

51. Turn the MEASUREMENT knob to the COMP position.

52. Press the $\frac{\text{OPERATE}}{\text{CAL}}$ button.

53. Turn the MEASUREMENT knob to the 100% OP position.

Note: After the external optics have been cleaned, this circuit has to be reset so that it will not continue to adjust the monitor for dust that is no longer present. Because these operations must be conducted at the control unit location, the auditor will have to leave the transmissometer location unless he can get assistance from someone at the control unit location.

2.3 CALIBRATION CHECK

Normally, the calibration check is performed using the portable audit device with an adjustable retroreflector (iris) to simulate clear stack conditions. The audit device and neutral desnity filters can be used to determine the linearity of the instrument response free of interference from varying stack opacity. This calibration check does not determine the actual instrument zero, or the status of the on-stack alignment.

A true calibration check can also be obtained by removing the on-stack components and setting them up in the control room, making sure that the proper pathlength and alignment are attained, and then placing the calibration filters in the measurement beam path.

2.3.1 Install Audit Device

54. Install the audit device by sliding it onto the transceiver.

    Note: The audit device will not slide until it is flush with the monitor. Care should be taken not to push it against the zero retroreflector.

55. Adjust the audit device iris to produce a 20 mA output current on the junction box meter (Figure 2-5) to simulate the amount of light returned to the transceiver during clear stack conditions.

    Note: If two people are performing the audit, zero the chart recorder response instead of using the 20 mA reading on the junction box.

56. Allow three or thirteen minutes (depending upon the use of an averaging circuit) for the junction box meter to display a stable reading and for the chart recorder to log the opacity vlaue.

57. Record the time at the end of the waiting period on blank 27.

2.3.2 Insert Low Range Filter

58. Insert the low range neutral density filter.

59. Wait for three or thirteen minutes (depending upon the averaging circuit employed) for the chart recorder to record the opacity value.

60. Record the time at the end of the waiting period on blank 28.

61. Record the low range neutral density filter's opacity value on blank 29 and serial number on blank 30.

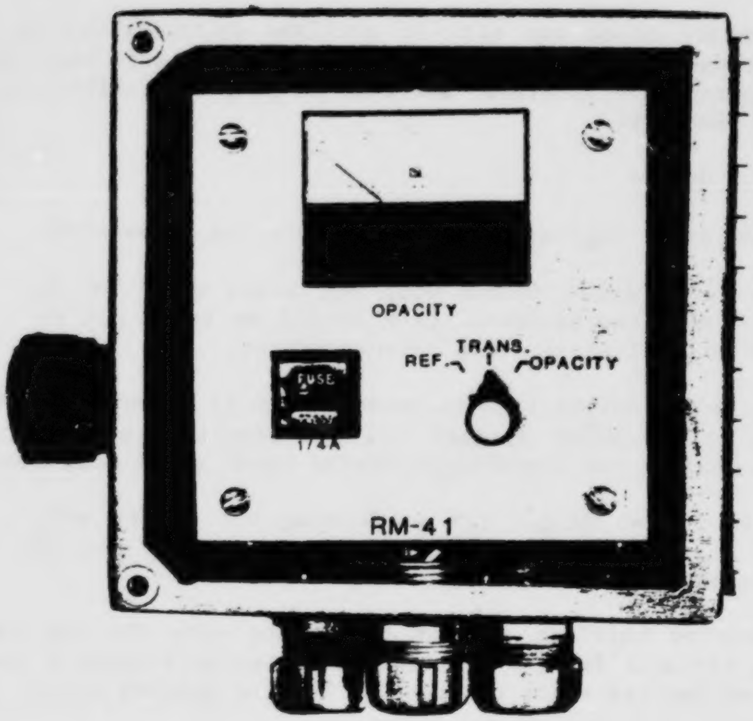

OPACITY
TRANS.
REF.
OPACITY
FUSE
1/4A
RM-41

Figure 2-5. Lear Sielger RM41 Junction Box

2.3.3 Insert Mid range Filter

62. Remove the low range filter from the audit device.

63. Check to see if the reading displayed on the junction box meter returns to 20 mA. If the reading is not 20 mA, the calibration check should be started over (go to Section 2.3.1).

64. If the 20 mA reading has been maintained, insert the mid range neutral density filter.

65. Repeat procedures in Section 2.3.2.

66. Record time, filter opacity value, and filter serial number on blanks 31, 32, and 33, respectively.

2.3.4 Insert High Range Filter

67. Repeat procedures in Section 2.3.3 using the high range filter.

68. Record time, filter opacity value, and filter serial number on blanks 34, 35, and 36, respectively.

2.3.5 Monitor Response Repeatability

69. Repeat procedures in Sections 2.3.2, 2.3.3, and 2.3.4, until a total of five opacity readings are obtained for each neutral density filter.

70. Record the time for each test on blanks 37 through 48.

71. Once the calibration check is finished, remove the audit device, close the protective cover on the junction box and close the transceiver head.

2.3.6 Post Cleaning Zero Compensation and Fault Indicator Check

72. Return to the control unit location to perform these final monitor checks.

73. Note and record any fault lamps illuminated on the control panel on blanks 5 through 9, and note that the fault occurred during the audit.

74. Initiate the monitor zero mode by pressing the $\frac{\text{OPERATE}}{\text{CAL}}$ button.

75. Turn the MEASUREMENT knob to the COMP position.

76. Record the zero compensation optical density value on the control panel meter on blank 49.

77. then return the monitor to the operate mode by pressing the $\frac{\text{OPERATE}}{\text{CAL}}$ button again.

78. Mark the time of day on the chart recorder.

79. Return the MEASUREMENT knob, the opacity range switch (on "opacity" circuit board), and the optical density range switch (on "optical density" circuit board) to their original positions.

Note: This information is found on blanks 10, 12, and 15, respectively.

2.4 PERFORMANCE AUDIT DATA RETRIEVAL

Retrieve the opacity data found on the chart recorder as follows:

2.4.1 Retrieve Retroreflector Window Check Data

80. Locate opacity reading immediately before stated time on blank 24.

81. Record opacity reading on blank 50.

82. Locate opacity reading recorded after the appropriate time interval (three or thirteen minutes) from the time on blank 24.

83. Record opacity reading on blank 51.

2.4.2 Retrieve Transceiver Window Check Data

84. Locate opacity reading corresponding to the time stated on blank 25.

85. Record opacity reading on blank 52.

86. Locate opacity reading recorded after the appropriate time interval (three or thirteen minutes) from the time on blank 26.

87. Record opacity reading on blank 53.

2.4.3 Retrieve Audit Device Installation Data

88. Locate the opacity reading immediately after stated time on blank 27.

89. Record the opacity value on blank 54.

2.4.4 Retrieve Low Range Filter Data

90. Locate the opacity reading immediately after stated time on blank 28.

91. Record the opacity value on blank 55.

2.4.5 Retrieve Mid range Filter Data

92. Locate the opacity reading immediately after stated time on blank 31.

93. Record the opacity value on blank 56.

2.4.6 Retrieve High Range Filter Data

94. Locate the opacity reading immediately after stated time on blank 34.

95. Record the opacity value on blank 57.

2.4.7 Retrieve Monitor Response Repeatability Data

96. Locate the opacity readings corresponding to the times stated on blanks 37 through 48.

97. Record the opacity values on blanks 58 through 69, respectively.

2.5 ANALYSIS OF PERFORMANCE AUDIT DATA

This section pertains to the analysis of the performance audit data. Specific criteria for the different monitor checks are stated to provide a means to determine which areas of the monitoring system are performing correctly. The areas that are not within the stated specifications should be addressed and corrected. The following analyses are not a complete listing of all of the problems that may affect monitor accuracy, but they do address the most frequent problems. These analyses will normally provide sufficient information to assess the accuracy of the monitor data and to indicate the deficiencies within the monitoring system.

2.5.1 True Assessment of Opacity Monitor Performance

A true assessment of the opacity monitor performance could be determined if clear stack conditions were present, or if the source allowed the on-stack monitoring components to be removed from the stack and tested in a dust-free environment (the same on-stack alignment and pathlength must be achieved). These two situations are not normally possible. Therefore, the following performance audit analyses are necessary to ascertain the specific problem areas within the monitoring system. These analyses provide qualitative and quantitative assessment of the transmissometer performance.

2.5.2 Stack Exit Correlation

The pathlength correction error on blank 70 should be within ± 2%. The error exponentially affects the opacity readings and the error in the opacity readings may be greater than or less than the stack exit correction error, depending upon the opacity measured. The most common error in computing the optical pathlength ratio (OPLR) is the use of the flange-to-flange distance rather than the stack/duct inside diameter. (The OPLR is factory-set and the user should not attempt adjustments without consulting the manufacturer.)

2.5.3 Control Panel Meter Correction Factor

The accuracy of the control panel meter is determined by comparing the control panel meter readings to the specified values for the internal span filter. The errors in the control panel meter should not affect the opacity data reported by the monitoring system unless the control panel meter is used to adjust the zero and span functions. The correction factors associated with the control panel meter are found on blanks 71, 72, and 73. Even though it is not essential that control be accurate, the source should adjust the panel meter so that the correction factors fall within a range of 0.98 to 1.02. Since the control panel meter error is determined by using the span filter, any change in the specified values for the span filter will cause an erroneous assessment of the control panel meter errors. The span filter value may change due to ageing, replacement, etc. Each time the monitor is thoroughly calibrated, the internal span filter should be renamed (new specified values); the latest values determined for the span filter should be used in all applicable analyses. A panel meter error of greater than 10% indicates a different monitor problem, which should become apparent once the audit has been completed.

2.5.4 Analysis of Reference Signal Error

The reference signal is a measure of the electronic alignment of the transceiver. The reference signal error on blank 74 should be within ± 10%; however, the opacity data may still be accurate if the REF lamp is on. Large errors in the reference signal may directly affect the opacity data. The most common causes for reference signal error are difficulties with the electronic alignment and/or decreased lamp output due to failure of the automatic gain control circuitry or lamp ageing (i.e., the lamp must be replaced).

2.5.5 Zero Compensation Analysis

The amount of automatic zero correction of the instrument (measured by the zero compensation check) should not exceed 4% opacity. The zero compensation is displayed in units of optical density; an optical density of 0.0177 is equal to 4% opacity. The zero compensation recorded on blank 14 should be within ± 0.018 OD. (The opacity data may still be accurate if the zero compensation exceeds 0.018 OD.) The zero compensation (after cleaning the tranceiver window and zero retroreflector)value on blank 49 should approach 0.000 OD, since all optical surfaces should be clean.

A residual zero compensation after a thorough cleaning of transmissometer optics is normally the result of an incorrect zero compensation circuit adjustment rather than malfunction of the circuit. If the zero compensation is within the proper range before the optics are cleaned, but goes negative after the transceiver optical surfaces are cleaned, it is probable that the zero compensation circuit was last adjusted by the source at a time when the optical surfaces were not clean. Often this situation occurs (adjustments during dirty window conditions), the internal zero will also have been adjusted to read 0% opacity, and thus, the zero will be off scale in the negative direction after the optics are cleaned; both the internal zero and the zero compensation circuit will need to be adjusted by the source at a time when the optics are clean.

2.5.6 Internal Zero and Span Calculation

The internal zero and span opacity responses on the chart recorder should agree within ± 2% opacity with the manufacturer's specified values; therefore, the span error (blank 77) and the zero error (blank 13) should be within ± 2% opacity.

The RM41 internal zero should be set to indicate 0% opacity; the difference between the internal zero and 0% opacity is the zero error. A zero error greater than 2% opacity is usually due to excessive dust accumulation on the optical surfaces, electronic drift, or chart recorder offset. Excessive dust on the optical surfaces would cause the WINDOW fault lamp to be illuminated and the zero compensation reading to be above 0.018 OD. Electronic drift is caused by inadequate electronic alignment maintenance procedures, which may also result in span values being outside the recommended range.

If the zero error is due to a chart recorder offset, the zero and span errors will be in the same direction and magnitude; the opacity data will be offset in the same manner.

Instrument span errors may be caused by the same problems that cause zero errors and may be identified in a similar fashion. A span error also may be caused by an inaccuarate assessment of the span filter value. This problem is discussed in Section 2.5.3.

2.5.7 Transmissometer Dust Accumulation Analysis

The opacity of the transceiver optical surface (blank 78) and the opacity of the retroreflector optical surface (blank 79) are combined to determine the total dust accumulation on the monitor's optical surfaces. The opacity of the optical surfaces (blank 80) should be ≤ 4%. A dust accumulation value of more than 4% opacity indicates that the airflow of the purge system and/or the cleaning frequency of the optical surfaces are inadequate. When determining the optical surface dust accumulation, the auditor should note whether the stack opacity is fairly stable (within ± 1% opacity) before and after the cleaning of the optical surfaces.

The accuracy of the zero compensation circuit can be checked through the use of the dust accumulation analysis results. The change between the zero compensation circuit optical density readings should be equivalent to the change between the effluent opacity readings before and after cleaning of the transceiver optics. The following relationship should be true if the zero compensation circuit is working properly and if an accurate assessment of dust depostion (in % opacity) was made.

$$(\underline{\text{Blank 78}}) = (1-10^{-2(\underline{\text{Blank 4}})[(\underline{\text{Blank 14}}) - (\underline{\text{Blank 49}}]}) \times 100$$

2.5.8 Calibration Check Analysis Calculation

To compare the chart recorder opacity responses to the opacity values of the neutral density filters, the filter values must be corrected to stack exit conditions according to the equations in the audit data sheets (audit analysis step E). The calculations are based on the assumption that the audit device produced a zero response on the chart recorder (i.e., the value found on blank 54 is 0% Op). If this is not the case, the expected monitor responses to the audit filters (blanks 81 through 83 must be corrected to account for this zero offset as follows:

$$Op_{adj} = [1 - (1 - \frac{Op_{ftr}}{100})(1 - \frac{Op_{zero}}{100})]$$

where: Op_{adj} = Correct monitor response

Op_{ftr} = filter opacity, corrected to stack exit conditions

Op_{zero} = audit device zero offset (monitor opacity response to audit device without filter)

The calibration errors for the three audit filters on blanks 111, 112, and 113 should be $\leq$ 3% opacity.

Biases in the monitor responses to the audit filters are due to misadjustment of the zero and span functions or to calibration of the monitor with neutral density filters that have not been corrected by the monitor's optical pathlength correlation factor. If the zero and span are not within the proper range, the calibration check data will often be biased in the same direction as the zero and span errors. Even if the zero and span errors are within the proper ranges, the monitor may still not be electronically aligned (i.e., the monitor should be adjusted to indicate 0% opacity during clear stack conditions). If the monitor is calibrated using neutral density filters (usually off-stack) without applying the optical pathlength correction factor to the filters, the monitor responses will agree with the audit filters before they have been corrected to stack exit conditions. If this is the case, the monitor should be recalibrated according to the annual recalibration procedure.

3. DYNATRON, INC., MODEL 1100

OPACITY MONITORING SYSTEM

The Dynatron 1100 opacity monitor system consists of three major components: the transmissometer, the air-purging system, and the remote control and data acquisition equipment. The transmissometer component consists of an optical transmitter/receiver (transceiver) unit mounted on one side of a stack or duct and a retroreflector unit mounted on the opposite side. The transceiver unit contains a light source, a photodiode detector, and associated electronics, and its output is transmitted to a control unit, which indicates optical density and stack exit opacity. Figure 3-1 illustrates the general arrangement block diagram of the Dynatron 1100.

The Dynatron control unit (Figure 3-2) has several options. The opacity/optical density display may be either an analog meter or a digital readout. A counter timer records the amount of time the opacity exceeds a source selected limit. An EPA Zero Span Calibration Check unit performs the zero and span functions as required for sources subject to Performance Specification 1. An integrated chart recorder is also available for the control unit.

The Dynatron transceiver uses a single-lamp, dual-detector system to measure opacity. During normal operation, the light from the measurement lamp is split into two beams - a measurement beam and a reference beam. The measurement beam is projected across the stack and returned by the retroreflector to the measurement detector. The reference beam is transported via fiber optics to the reference detector, which is identical to the measurement detector. The stack opacity is determined by computing the ratio of the output of the two detectors; therefore, the absolute intensity of the measurement lamp will not affect the accuracy of the opacity readings.

The zero and span checks are performed by turning off the measurement lamp and alternately illuminating two calibration lamps. When the "zero" calibration lamp is on, a beam splitter and fiber optics bundle splits the light into two portions, which are directed onto the measurement and reference detectors. The electronic circuitry determines the ratio of the measurement detector response to the reference detector response; this ratio (the monitor "zero" check) is independent of the intensity of the calibration and measurement lamps. The span check is accomplished by turning on the span calibration lamp. The light from this lamp is split into two portions, approximately one half is directed to the reference detector. The remaining portion of light is passed through a neutral density filter and then directed onto the measurement detector. The electronic circuitry then determines the ratio of the measurement detector response to the reference detector response; this ratio (the monitor span check), like the zero check ratio, is insensitive to calibration measurement lamp intensity differences.

The air-purging system serves a threefold purpose: (1) it provides an air window to keep exposed optical surfaces clean; (2) it protects the optical surfaces from condensation of moisture from stack gases; and (3) it minimizes thermal conduction from the stack to the instrument. A standard installation

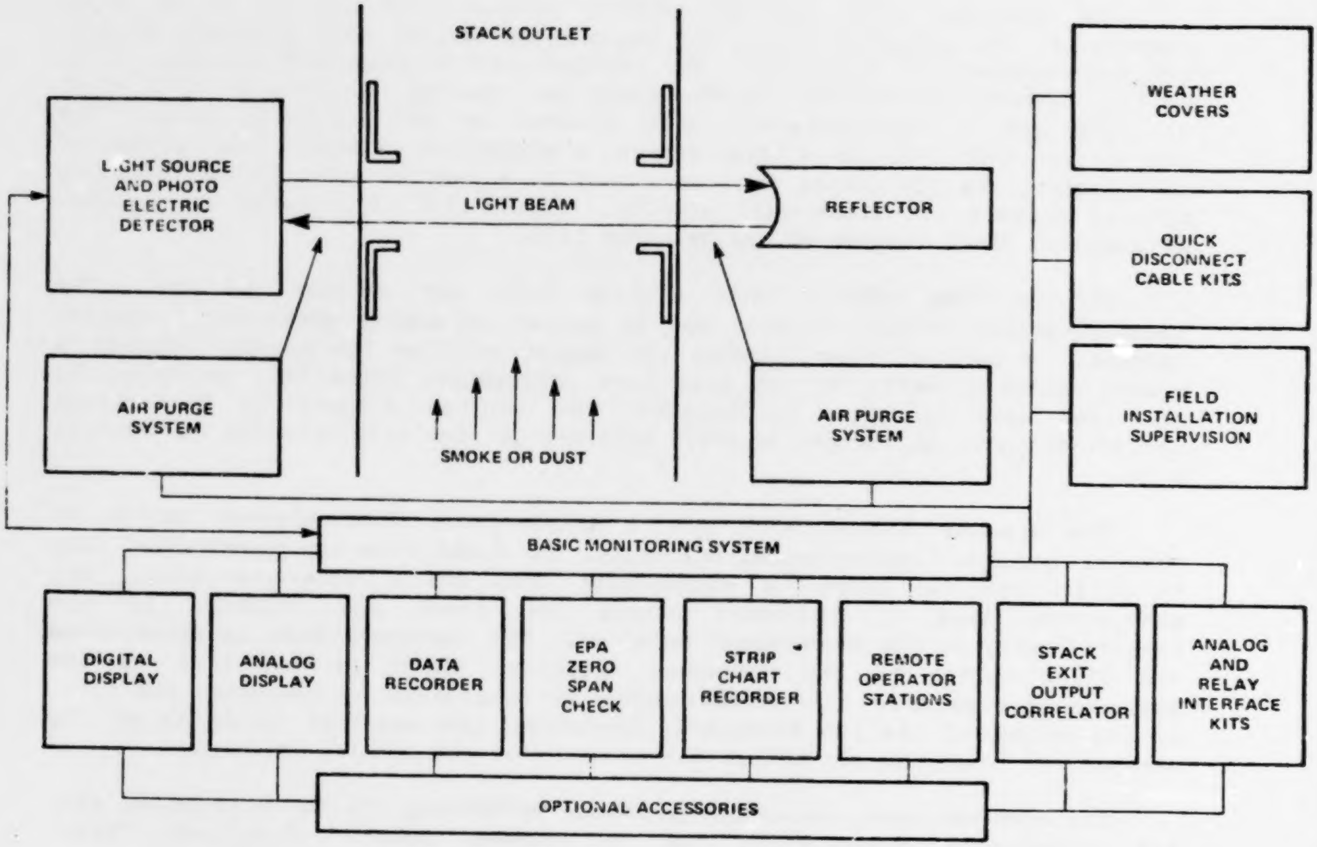
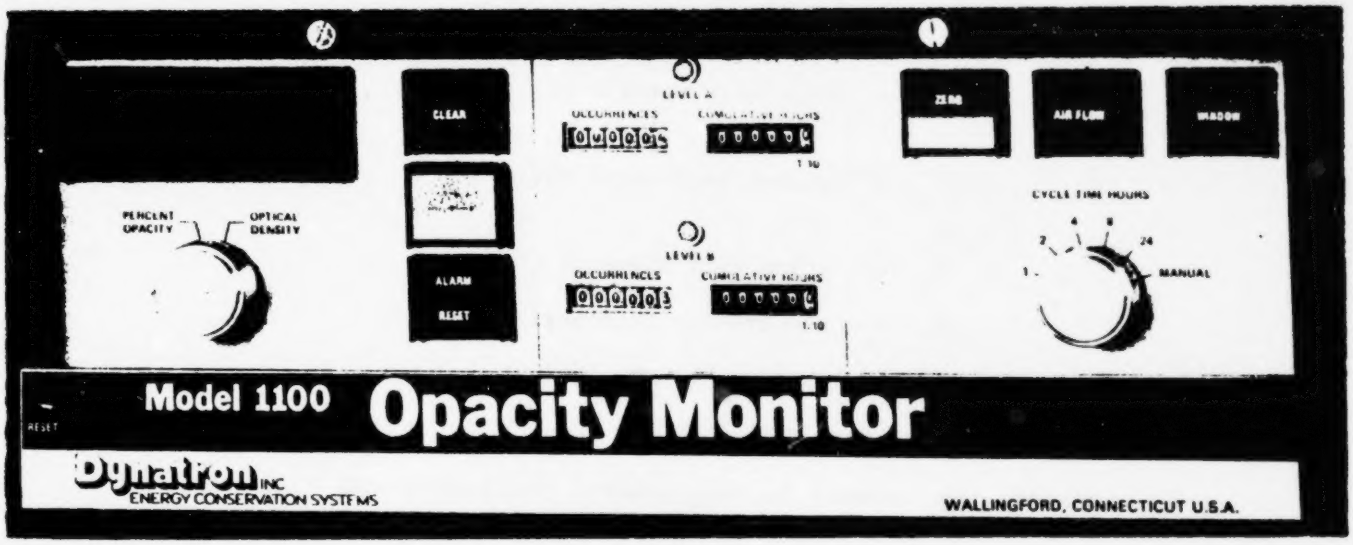

STACK OUTLET
LIGHT SOURCE AND PHOTO ELECTRIC DETECTOR
LIGHT BEAM
REFLECTOR
WEATHER COVERS
QUICK DISCONNECT CABLE KITS
FIELD INSTALLATION SUPERVISION
AIR PURGE SYSTEM
SMOKE OR DUST
AIR PURGE SYSTEM
BASIC MONITORING SYSTEM
DIGITAL DISPLAY
ANALOG DISPLAY
DATA RECORDER
EPA ZERO SPAN CHECK
STRIP CHART RECORDER
REMOTE OPERATOR STATIONS
STACK EXIT OUTPUT CORRELATOR
ANALOG AND RELAY INTERFACE KITS
OPTIONAL ACCESSORIES

Figure 3-1. Dynatron 1100 General Arrangement Block Diagram


CLEAR
LEVEL A
OCCURRENCES
CUMULATIVE HOURS
ZERO
AIR FLOW
WINDOW
CYCLE TIME HOURS
PERCENT OPACITY
OPTICAL DENSITY
LEVEL B
ALARM
RESET
MANUAL
Model 1100 Opacity Monitor
Dynatron INC
ENERGY CONSERVATION SYSTEMS
WALLINGFORD, CONNECTICUT U.S.A.

Figue 3-2. Dynatron Control Unit

has one air-purging system for the transceiver unit and one for the retroreflector unit; each system has a blower that provides filtered air.

3.1 STACK EXIT OPACITY DETERMINATION

The opacity monitor measures the amount of light transmitted across the stack and returned from the retroreflector. The control unit uses this information to calculate the optical density of the effluent stream at the monitor location. The optical density measurements are corrected for pathlength differences between the measurement site and the stack exit and converted to opacity. The relationship between stack exit opacity and optical density is described by the following equation:

$$Op_x = 1 - 10^{-(Lx/Lt)(OD)}$$

where: Op_x = stack exit opacity (%)

$\frac{L_x}{L_t}$ = optical pathlength ratio

L_x = stack exit diameter (ft)

L_t = measurement pathlength (ft)

OD = transmissometer optical density

3.1.1 Stack Exit Correlation Error

1. Measure the correct transmissometer pathlength and stack exit diameter.

2. Record the stack exit inside diameter and the transmissometer pathlength on blanks 1 and 2, respectively, of the Dynatron 1100 Performance Audit Data Sheet in Appendix C.

   > Note: If actual measurements are not practical, obtain the data from detailed plant blueprints or from other available source information. The monitor pathlength is two times the length of the inside diameter of the stack at the monitor installation location.

3. Calculate the pathlength ratio using the above equation.

4. Record the value on blank 3.

5. Obtain the preset pathlength ratio used by the monitor.

6. Record the value on blank 4.

Note: The pathlength ratio is preset by the manufacturer using information supplied by the source. The origin of the pathlength ratio should be noted.

3.2 MONITORING SYSTEM CHECK

This section describes procedures to gather pertinent operating parameters necessary to ascertain whether the monitoring system is functioning properly. Sections 3.2.1 and 3.2.2 address control unit parameters; tests for these parameters are performed at the Dynatron control unit location. Sections 3.2.3 through 3.2.6 describe the test procedures performed at the monitoring site to determine the status of the optical surfaces and the transmissometer alignment.

Many of the procedures call for a waiting period at the conclusion of an audit step to ensure that the strip chart recorder has had sufficient time to stabilize and record a steady response. For recorders displaying instantaneous opacity readings, a waiting interval of three minutes should be sufficient. For recorders displaying six-minute averages, a waiting period of thirteen minutes is recommended. At a later time during the audit, the auditor retrieves the recorded opacity data corresponding to the specific audit steps.

Although the audit can be conducted by one person, the waiting intervals can be significantly reduced if two people are present. The second person can stay with the strip chart recorder and record the necessary data as soon as a steady reading occurs. Time is saved in decreased waiting intervals, and in the elimination of the transfer of data from the strip charts at the end of the audit.

3.2.1 Fault Indicators Check

The following list describes the fault lamps that are found on the Dynatron control unit panel. Unless otherwise noted, the audit analyses can continue with illuminated fault lamps, provided that the source has been informed of the fault conditions.

> Note: The other three lamps on the control unit (CLEAR, EARLY WARNING, and ALARM) are not fault indicators.

7. Record the status (ON or OFF) of the LAMP fault lamp on blank 5.

> Note: An illuminated LAMP fault lamp indicates low or nonexistent output of the measurement lamp. If the LAMP indicator is illuminated, the photodetector is not receiving sufficient light to accurately determine opacity. Plant personnel should be notified so that repairs or adjustments can be made after the audit. This indicator is located behind the faceplate at the bottom of the control unit.

8. Record the status (ON or OFF) of the WINDOW fault lamp on blank 6.

> Note: An illuminated WINDOW fault lamp indicates that the opacity (dust accumulation) of the transmissometer (transceiver) measurement window exceeds the limit selected by the source. The WINDOW indicator does not indicate monitor compensation for dust accumulation on optical surfaces.

9. Record the status (ON or OFF) of the AIR FLOW fault lamp on blank 7.

> Note: The AIR FLOW fault lamp indicates inadequate purge airflow to maintain the cleanliness of the optical surfaces. If the AIR FLOW lamp is illuminated, the source should be notified so that corrective measures can be initiated after the audit.

3.2.2 Internal Zero and Span Check

10. Record the position on blank 8 of the CYCLE TIME HOURS knob on the Dynatron control unit.

11. Turn that knob to the MANUAL position.

12. Record the position of the METER DISPLAY knob on blank 9.

13. Turn the knob to the OPACITY position.

14. Press the $\frac{\text{ZERO}}{\text{SPAN}}$ button to initiate the automatic calibration cycle.

> Note: The ZERO and SPAN lights should illuminate one at a time, for about three minutes each.

15. Record the zero and span responses displayed on the control panel meter on blanks 10 and 11, respectively, and those displayed on the chart recorder on blanks 12 and 13, respectively.

16. Locate (in the monitor's Operation Manual or maintenance logbook) and record the current zero and span values on blanks 14 and 15, respectively.

> Note: The zero and span checks provide a good indication of the electrical calibration of the monitoring system; however, these checks do not indicate optical misalignment or dirty windows. Also, these checks do not utilize the measurement lamp that is used during stack opacity measurements.

17. Mark the time of the day on the chart recorder paper.

3.2.3 Alignment Check

Note: This step applies only to monitors equipped with the optical alignment sight option.

18. Locate the alignment sight on the stack near the transceiver, and sight through the viewing glass.

    Note: The measurement beam should be a circle of light centered on the retroreflector. If the circle of light is not centered on the retroreflector, the monitor is not properly aligned. Instrument optical alignment has no effect on the zero and span responses; however, if the optical alignment is not correct, the stack opacity data will be biased high, since less light will be returned from the retroreflector.

19. Record whether the image is centered (YES or NO) on blank 16.

3.2.4 Transceiver Window Check

20. Allow the monitor to operate at least three minutes (thirteen minutes if monitoring system processes the data through a six-minute averaging circuit).

21. Remove the measurement window slide holder and clean the window.

22. Reinsert the measurement window.

23. Record the time of the day on blank 17.

24. Wait an additional three or thirteen minutes (depending upon the use of an averaging circuit) for the chart recorder to log the opacity.

3.2.5 Retroreflector Window Check

25. Repeat the procedure described in Section 3.2.4, except clean the retroreflector optical surface in lieu of the transceiver measurement window.

26. Record the time of the retroreflector optical surface cleaning on blank 18.

27. Wait an additional three or thirteen minutes (depending upon the use of an averaging circuit) before proceeding to the next step.

3.3 CALIBRATION CHECK

Normally, the calibration check (incremental) is performed by substituting neutral density slides in place of the transceiver measurement window. This check should be performed only when the stack opacity is fairly steady. The calibration check provides a determination of the linearity of the instrument response and the on-stack alignment status, since it utilizes all of the components of the measurement system. This calibration check does not provide a test of the actual instrument zero.

Only under clear stack conditions will the calibration check provide a check of the actual instrument zero, the instrument calibration, and the effect of on-stack alignment on the opacity data. A true calibration check can also be obtained by removing the on-stack components and setting them up in the control room, making sure that the on-stack pathlength and alignment are duplicated.

3.3.1 Insert Low Range Filter

28. Allow three or thirteen minutes (depending upon the use of an averaging circuit) before inserting the low range audit slide.

29. Record the time at the end of the waiting period on blank 19.

30. Remove the clear transceiver measurement window and insert the low range neutral density filter slide.

31. Wait another three or thirteen minutes for the chart recorder to log the combined opacity value of the slide and the effluent.

32. Record the time at the end of this second waiting period on blank 20.

33. Remove the low range audit slide.

34. Replace the transceiver measurement window.

35. Wait another three or thirteen minutes.

36. During this waiting period, record the audit filter's opacity value on blank 21 and serial number on blank 22.

37. Record the time at the end of this third waiting period on blank 23.

3.3.2 Insert Mid range Filter

38. Remove the measurement window.

39. Insert the mid range audit filter.

40. Wait three or thirteen minutes (depending upon the use of an averaging circuit).

41. Record the time at the end of the waiting period on blank 24.

42. Remove the mid range slide.

43. Replace the transceiver measurement window.

44. Wait another three or thirteen minutes.

45. During this second waiting period, record the audit filter's opacity value on blank 25 and serial number on blank 26.

46. Record the time at the end of the second waiting period on blank 27.

3.3.3 Insert High Range Filter

47. Remove the measurement window.

48. Insert the high range audit slide.

49. Wait three or thirteen minutes (depending upon the use of an averaging circuit).

50. Record the time at the end of the waiting period on blank 28.

51. Remove the audit slide.

52. replace the transceiver measurement window.

53. Record the slide's opacity value on blank 29 and serial number on blank 30.

3.3.4 Monitor Response Repeatability

54. Repeat the procedures in Sections 3.3.1, 3.3.2, and 3.3.3 until a total of five opacity readings is obtained for each neutral density slide.

55. Record the times for each test on blanks 31 through 54.

56. Remove the high range audit slide.

57. Replace the transceiver measurement window for the last time.

58. Wait an additional three or thirteen minutes.

59. Record the time at the end of this final waiting period on blank 55.

> Note: Once the calibration check is completed, return to the control room.

60. Return the control unit knobs to their original positions (the data responses on blanks 8 and 9).

3.4 PERFORMANCE AUDIT DATA RETRIEVAL

61. Return to the chart recorder, and mark the time of the day on the chart recorder paper. Retrieve the opacity data found on the chart recorder.

3.4.1 Retrieve Transceiver Window Check Data

62. Locate the opacity reading immediately before the stated time on blank 17.

63. Record this opacity reading on blank 56.

64. Locate the opacity reading recorded after the appropriate time interval (three or thirteen minutes) from the time on blank 17

65. Record the opacity reading on blank 57.

3.4.2 Retrieve Retroreflector Window Check Data

66. Perform the same operation as described in Section 3.4.1 for the stated time on blank 18.

67. Record the opacity readings on blanks 58 and 59.

3.4.3 Retrieve Low Range Filter Data

68. Locate the opacity reading immediately after the stated times on blanks 19, 20, and 23.

69. Record the opacity values on blanks 60, 61, and 62, respectively.

3.4.4 Retrieve Mid range Filter Data

70. Locate the opacity reading immediately after the stated times on blanks 24 and 27.

71. Record the opacity values on blanks 63 and 64.

3.4.5 Retrieve High Range Filter Data

72. Locate the opacity reading immediately after the stated time on blank 28.

73. Record the opacity value on blank 65.

3.4.6 Retrieve Monitor Response Repeatability Data

74. Locate the opacity readings (as in Sections 3.4.3, 3.4.4, and 3.4.5) corresponding to the times stated on blanks 31 through 55.

75. Record the opacity values on blanks 68 through 90, respectively.

3.5 ANALYSIS OF PERFORMANCE AUDIT DATA

This section addresses the analysis of the performance audit data. Specific criteria for the different monitor checks are stated to provide a means to determine which areas of the monitoring system are performing correctly. The areas that are not within the stated specifications should be addressed and corrected.

The following analyses are not a complete listing of all of the problems that may affect the monitor accuracy, but they do address the most frequent problems. These analyses will normally provide the auditor with sufficient information to assess the accuracy of the monitor data and to indicate the deficiencies within the monitoring system.

3.5.1 True Assessment of Transmissometer Performance

A true assessment of the opacity monitor performance could be determined if clear stack conditions were present or if the source allowed the on-stack monitoring components to be removed from the stack and tested in a dust free environment, (the same on-stack alignment and pathlength must be achieved). These two situations are not normally possible. Therefore, the following performance audit analyses are necessary to ascertain the specific problem areas within the monitoring system. These analyses provide a qualitative and quantitative assessment of the performance of the transmissometer.

3.5.2 Stack Exit Correlation

The pathlength correction error on blank 91 should be within ± 2%. The error exponentially affects the opacity readings; the error in the opacity readings may be greater than or less than the stack exit correction error depending upon the opacity measured. The most common error in computing the optical pathlength ratio is the use of the flange-to-flange distance rather than the stack/duct inside diameter. The pathlength ratio is factory-set and the user should not attempt adjustments without consulting the manufacturer.

3.5.3 Control Panel Meter Correction Factor

The accuracy of the control panel meter is determined by comparing the control panel readings to the specified value for the internal span filter. The errors in the control panel meter should not affect the opacity data reported by the monitoring system, unless the control panel meter is used to adjust the zero and span signals. The correction factor associated with the control panel meter is found on blank 92. Even though it is not essential that the control panel meter be accurate, the source should adjust the panel meter so that the correction factor falls within a range of 0.98 to 1.02. Since the control panel meter error is determined by using the span filter, any change in the specified values for the span filter will cause an erroneous assessment of the control panel meter errors. The span filter value may change due to ageing, replacement, etc. Each time the monitor is thoroughly calibrated, the internal span filter should be renamed (new specified values); the latest values determined for the span filter should be used in all applicable analyses. A meter error of greater than 10% indicates a different monitor problem which should become apparent once the audit has been completed.

3.5.4 Internal Zero and Span Error Calculation

The internal zero and span opacity responses on the chart recorder (blank 93 and blank 94, respectively) should agree within ± 2% opacity with the manufacturer's specified values.

Since the Dynatron 1100 internal zero and span functions are performed inside the transceiver, dust accumulation on the exposed optical surfaces does not affect the zero or span functions. The zero and span functions will, however, be affected by electronic drift and/or a chart recorder offset. Zero or span errors due to electronic drift result from inadequate electronic alignment maintenance procedures. Electronic drift may cause the errors to be additive or to cancel one another. A chart recorder offset will cause the zero and span functions to be offset in the same direction and magnitude; the opacity data will also be offset in the same manner.

3.5.5 Transmissometer Dust Accumulation Analysis

The opacity of the transceiver window (blank 95a) and the opacity of the retroreflector window (blank 95b) are combined to determine the total dust accumulation on the monitor's optical surfaces. The opacity of the optical surfaces (blank 95c) should be ≤ 4% Op. A dust accumulation value of more than 4% opacity indicates that the airflow of the purge system and/or the cleaning frequency of the optical surfaces are inadequate. When determining the optical surface dust accumulation, the auditor should note whether the stack opacity is fairly stable (within ± 1% opacity) before and after the cleaning of the optical surfaces.

3.5.6 Calibration Check Analysis Calculation

Since the stack opacity is measured in conjunction with the audit slides, the chart recorder displays the combined effect. To compare the chart recorder opacity responses with the opacity values of the neutral density slides, the slide values (corrected to stack exit conditions, analysis Step E) have to be combined with the stack opacity (analysis Steps F, H, and J). The stack opacity during the combined measurement is assumed to equal the average of the measured stack opacity before and after the insertion of an audit slide. The calibration errors for the three audit slides (blanks 141, 142, and 143) should be ≤ 3% opacity.

Biases in the monitor responses to the audit filters are due to misadjustment of the zero and span functions or to calibration of the monitor with neutral density filters that had not been corrected by the monitor's optical pathlength correlation factor. If the zero and span are not within the proper range, the calibration check data will often be biased in the same direction as the zero and span errors. Even if the zero and span errors are within the proper ranges, the monitor may still not be electronically aligned (i.e., the monitor should be adjusted to indicate 0% opacity during clear stack conditions). If the monitor is calibrated using neutral density filters (usually off-stack) without applying the optical pathlength correction factor to the filters, the monitor responses will agree with the audit filters before they have been corrected to stack exit conditions. If this is the case, the monitor should be recalibrated according to the annual recalibration procedure.

4. CONTRAVES GOERZ CORPORATION, MODEL 400

OPACITY MONITORING SYSTEM

The Contraves Goerz transmissometer system consists of three major components: the transmissometer, the air-purging and shutter system, and the remote control and data acquisition equipment. The transmissometer component consists of an optical transmitter/receiver (transceiver) unit mounted on one side of a stack or duct and a retroreflector unit mounted on the opposite side. The transceiver unit contains a light source, a photodiode detector, and associated electronics, and its output is transmitted to a control unit, which indicates optical density and stack exit opacity. Figure 4-1 illustrates the general arrangement of the transmissometer transceiver and reflector units on the stack.

The transceiver uses a single lamp, single detector system and dual chopper to determine opacity. The first chopper located inside the optical compartment modulates the light beam to eliminate interference from ambient light. The second chopper is divided into three sections that serve zero, span, and measurement functions. The second chopper is exposed to the stack effluent, and it automatically adjusts for dust accumulation on the measurement window of the transceiver.

The air-purging system serves a threefold purpose: (1) it provides an air window to keep exposed optical surfaces clean; (2) it protects the optical surfaces from condensation of moisture from stack gases; and (3) it minimizes thermal conduction from the stack to the instrument. A standard installation has one air-purging system for the transceiver unit and one for the retroreflector unit; each system has a blower that provides filtered air.

The shutters automatically provide protection for the exposed optical surfaces from smoke, dust, and the stack gas. Each shutter is held in place (out of the optical path) by the passing purge air. When the airflow is interrupted, the shutter drops into place to protect the external optics and opens automatically upon restoration of power to the blowers.

The optional control unit (Figure 4-2; one of two available units) is used to convert the nonlinear transmittance output from the transceiver into linear opacity and optical density measurements. It also corrects the opacity measurement according to the ratio of the stack exit diameter to the transmissometer pathlength, known as the Stack Taper Ratio (STR).

Note: Contraves Goerz also markets three new control units: M500, M700, and M701; however, these units are not in wide use at this time, and are not discussed in this report.

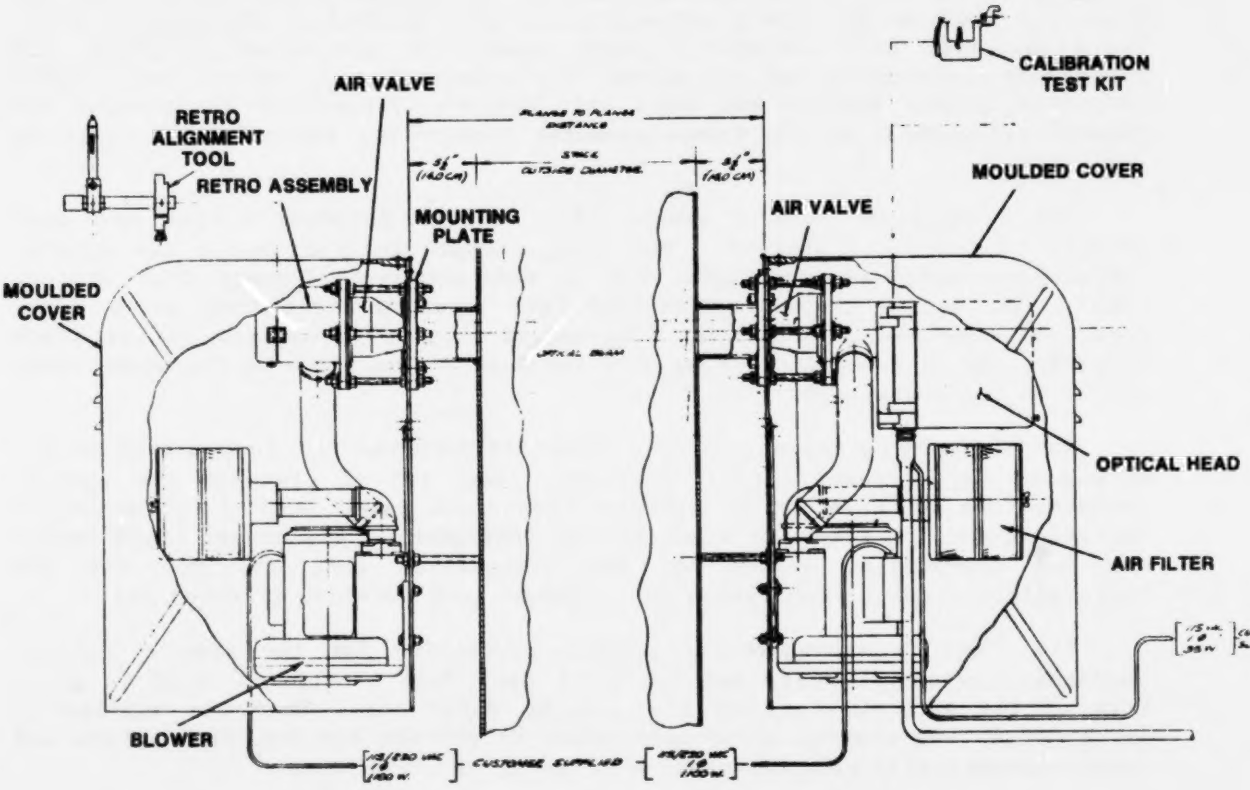

CALIBRATION TEST KIT
AIR VALVE
RETRO ALIGNMENT TOOL
RETRO ASSEMBLY
FLANGE TO FLANGE DISTANCE
STACK OUTSIDE DIAMETER
5½" (14.0 CM)
5½" (14.0 CM)
MOUNTING PLATE
MOULDED COVER
AIR VALVE
MOULDED COVER
OPTICAL BEAM
OPTICAL HEAD
AIR FILTER
115 VAC 1 Ø 35 W
CUSTOMER SUPPLIED
BLOWER
115/230 VAC 1 Ø 1100 W.
CUSTOMER SUPPLIED
115/230 VAC 1 Ø 1100 W.

Figure 4-1. Contraves 400 General Arrangement

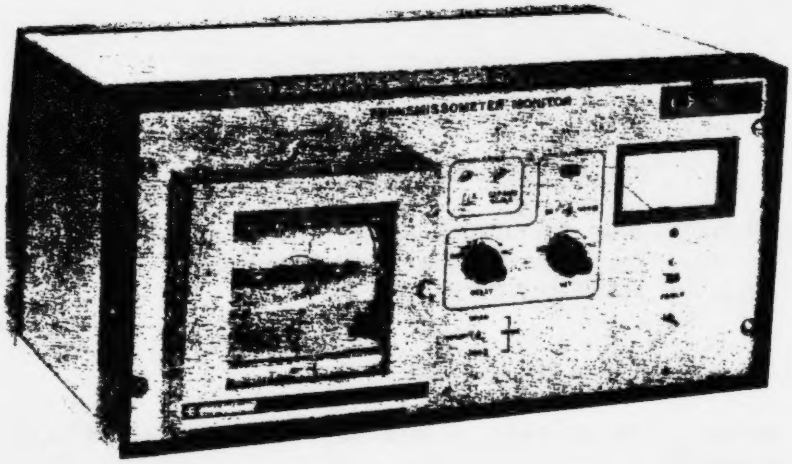

TRANSMISSOMETER MONITOR

Figure 4-2. Contraves 400 Control Unit

4.1 STACK EXIT OPACITY DETERMINATION

The opacity monitor measures the amount of light transmitted across the stack and returned from the retroreflector. The control unit uses this information to calculate the optical density of the effluent stream at the monitor location. The optical density measurements are corrected for pathlength differences between the measurement site and the stack exit and are then converted to opacity. The relationship between stack exit opacity and optical density is described by the following equation:

$$Op_x = 1 - 10^{-(STR)(OD)}$$

where: Op_x = stack exit opacity (%)

$STR = \frac{L_x}{L_t}$; optical pathlength ratio

L_x = stack exit diameter (ft)

L_t = measurement pathlength (ft)

OD = transmissometer optical density

Even though the Contraves Goerz M400 transmissometer is a dual-pass monitor, use the single-pass measurement pathlength (L_t) to calculate the STR, not two times the stack inside diameter.

4.1.1 Stack Exit Correlation Error

1. Measure the correct transmissometer pathlength and stack exit diameter.

2. Record the stack exit inside diameter and the transmissometer pathlength on blanks 1 and 2, respectively, on the Contraves Goerz 400 Performance Audit Data Sheet in Appendix D.

   Note: If actual measurements are not practical, obtain the data from detailed plant blueprints or other available source information. The monitor pathlength is the length of the inside diameter of the stack at the monitor installation location.

3. Calculate the STR (divide the value on blank 1 by the value on blank 2).

4. Record the value on blank 3.

5. Obtain the preset STR used by the monitor.

6. Record the value on blank 4.

   Note: The origin of the STR value should be noted.

4.2 MONITORING SYSTEM CHECK

This section describes checks to gather pertinent operating parameters necessary to ascertain whether the monitoring system is functioning properly. The control unit parameters are addressed within the procedures found in Sections 4.2.1 through 4.2.3; tests for these parameters are not required if the source does not have a control unit. If the source does have a control unit, Sections 4.2.5 and 4.2.6 can be eliminated, since the zero and span checks are performed at the control unit. The test procedures described in Sections 4.2.5 through 4.2.9 are performed at the transmissometer location to determine the status of the optical surfaces and the transmissometer alignment.

Many of the procedures call for a waiting period at the conclusion of an audit step to ensure that the strip chart recorder has had sufficient time to stabilize and record a steady response. For recorders with instantanenous opacity displays, a waiting interval of three minutes should be sufficient. For recorders displaying only six-minute averages, a waiting period of thirteen minutes is recommended. At a later time during the audit, the auditor retrieves the recorded opacity data corresponding to the specific audit steps.

Although the audit can be conducted by one person, a second person can significantly reduce the waiting intervals and audit time. The second person can save time by staying with the strip chart recorder and recording the necessary data as soon as a steady reading occurs.

4.2.1 Fault Indicators Check

There are two commonly encountered control units available from Contraves. One has two fault lamps, and it is available only with an analog readout (see Figure 4-2). The other newer unit has five fault lamps and an option for digital readout. Since the newer unit includes the two fault indicators on the old control unit, the newer control unit fault lamps are described. The fault lamps on the second unit can blink rapidly or remain illuminated. A blinking lamp does not indicate a fault but an illuminated lamp does indicate a fault. Unless otherwise noted, the audit analyses can continue with illuminated fault lamps, provided that the source has been informed of the fault conditions. The following list describes the fault lamps.

7. Record the status (ON or OFF) of the CAL FAULT lamp on blank 5.

   Note: The CAL FAULT lamp indicates the zero or span value is out of the range specified by the manufacturer. A calibration fault is due to a change in the transceiver electronics and may affect the opacity data.

8. Record the status (ON or OFF) of the DIRTY WINDOW fault lamp on blank 6.

   Note: When the DIRTY WINDOW limit has been exceeded, the opacity data may be biased. This lamp indicates a need to clean the dirty window surfaces; however, it only monitors the transceiver window. (In older units the DIRTY WINDOW indicator is a red lamp under the WINDOW label.)

9. Record the status (ON or OFF) of the PURGE AIR fault lamp on blank 7.

   Note: If the PURGE AIR fault lamp is illuminated, the purge air blowers may not be working properly, or the filter element cleaning the purge air is dirty and restricting the airflow. Plant personnel should be informed if this lamp is on, so corrective measures can be initiated at the conclusion of the audit. (This fault lamp is not an indicator of dirt on the measurement window.)

10. Record the status (ON or OFF) of the STACK POWER FAILURE fault lamp on blank 8.

    Note: An illuminated STACK POWER FAILURE fault lamp indicates no power to the transceiver or to the purge air blowers. If this condition exists, power must be restored to the monitor before the audit can continue.

11. Record the status (ON or OFF) of the LAMP FAILURE fault lamp on blank 9.

    Note: An illuminated LAMP FAILURE fault lamp indicates that the photodetector is not receiving sufficient light to accurately determine opacity. Plant personnel should be notified so that the lamp can be replaced. The output of a new measurement lamp will be unstable for several hours after replacement; therefore, a calibration check should not be performed during this period.

12. Record the status (ON or OFF) of the ALARM fault lamp on blank 10.

    Note: An illuminated ALARM fault lamp indicates that the opacity exceeds a source selected limit. The alarm indicator provides process control information only; it is not an indicator of monitor performance.

4.2.2 Instrument Zero Check

13. Initiate the zero mode by turning the MODE switch on the control panel to the ZERO position (the orange CAL lamp will light)

14. Record the value on blank 11 displayed on the chart recorder.

    Note: The cross-stack zero is simulated by using the zero retroreflector portion of the chopper. The zero check provides an indication of the amount of dust on the measurement window and on the zero retroreflector portion of the chopper, and/or of the status of the electronic alignment of the instrument. It does not, however, provide an indication of dirty window conditions at the measurement retroreflector, nor of optical misalignment, nor of the true cross-stack zero.

4.2.3 Internal Span Check

15. Turn the MODE switch to the SPAN position to initiate the span mode.

16. Record the span value on blank 12 displayed on the control panel meter (0-100% Op scale) and the value displayed on the chart recorder on blank 13.

    Note: The span operation is automatically performed by the transceiver using the span retroreflector portion of the chopper. The span measurement provides another check of the electrical alignment and the linearity of the transmissometer response to opacity.

17. Turn the MODE switch to the NORMAL position to return the monitor to the opacity measurement mode.

18. Mark the time of the day on the chart recorder paper.

4.2.4 Span Value Check

19. Record the chopper span opacity value on blank 14 supplied by the manufacturer.

    Note: The span value is recorded on the first page of the "Operation Manual".

4.2.5 Zero Check at Transceiver

20. Open the black cover on the rear of the transceiver.

21. Turn the MODE switch to the ZERO position.

    Note: The MODE switch is on the right side of the transceiver meter.

22. Record the time of day and the transceiver meter response on blanks 15 and 16, respectively.

4.2.6 Span Check at Transceiver

23. Turn the MODE switch in the back of the transceiver to the SPAN position.

24. Record the time of day and the transceiver meter response on blanks 17 and 18, respectively.

    Note: Perform this step only if the monitoring system is not equipped with a control unit.

4.2.7 Alignment Check

25. Determine the monitor alignment by looking through the bull's eye on the back of the transceiver (Figure 4-3).

26. Observe and record whether the image is centered (blank 19).

    Note: Instrument optical alignment has no effect on the internal checks of the instrument; however, if the optical alignment is not correct, the opacity data will be biased high, since all the light transmitted to the retroreflector is not returned to the detector.

4.2.8 Retroreflector Window Check

27. Allow the monitor to operate at least three minutes (thirteen minutes if the monitoring system processes the data through a six-minute averaging circuit).

28. Clean the window of the measurement retroreflector.

29. Record the time of the measurement retroreflector window cleaning on blank 20.

30. Wait an additional three or thirteen minutes (depending upon the use of an averaging circuit) before proceeding to the next step.

4.2.9 Transceiver Window Check

31. Open the transceiver, stop the chopper, and install the audit device and the low range filter.

    Note: The external chopper should be stopped carefully to avoid bending its blades.

32. Adjust the audit device iris to produce a 10% opacity reading on the transceiver meter, and tighten the iris set screw.

    Note: If there are two people conducting the audit, the audit device iris should be adjusted so that the chart recorder displays a value of 10% opacity.

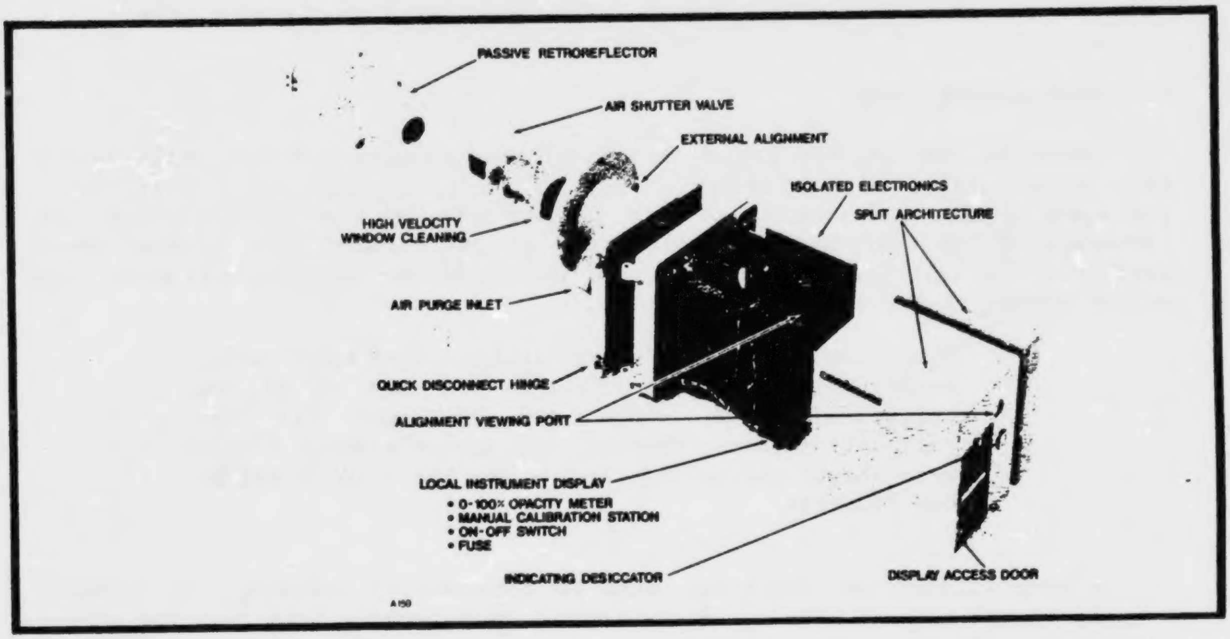

PASSIVE RETROREFLECTOR
AIR SHUTTER VALVE
EXTERNAL ALIGNMENT
ISOLATED ELECTRONICS
SPLIT ARCHITECTURE
HIGH VELOCITY WINDOW CLEANING
AIR PURGE INLET
QUICK DISCONNECT HINGE
ALIGNMENT VIEWING PORT
LOCAL INSTRUMENT DISPLAY
• 0-100% OPACITY METER
• MANUAL CALIBRATION STATION
• ON-OFF SWITCH
• FUSE
INDICATING DESICCATOR
DISPLAY ACCESS DOOR
A150

Figure 4-3. Contraves 400 Transceiver

33. Wait three or thirteen minutes (depending upon the use of an averaging circuit) for recording the precleaning opacity.

34. Remove the audit device/low range filter and chopper.

35. Clean the chopper and the transceiver measurement window.

36. Replace the chopper, the audit device, and the low range filter.

37. Record the time of the transceiver optical surface cleaning on blank 21.

38. Wait an additional three or twelve minutes (depending upon the use of an averaging circuit) before proceeding to the next step.

4.3 CALIBRATION CHECK

Normally, the calibration check is performed using a portable audit device with an adjustable retroreflector (iris) to simulate clear stack conditions. the audit device and neutral density filters can be used to determine the linearity of the instrument response free of interference from varying stack opacity. The calibration check does not determine the actual instrument zero or the status of the on-stack alignment.

> Note: Many sources which utilize Contraves Goerz monitors have an audit device (referred to as the calibration kit) which may be used for the calibration check; however, the source's audit device zero should not be adjusted, since the zero is set by the factory.

A true calibration check can also be obtained by removing the on-stack components and setting them up in the control room, making sure that the proper pathlength and aligmment are attained, and then placing the calibration filters in the measurement beam path.

4.3.1 Zero Audit Device

39. Remove the low range filter and adjust the audit device iris to produce a 0% opacity reading on the transceiver meter.

    > Note: If two people are performing the audit, adjust the iris until the chart recorder displays a 0% opacity value.

40. Tighten the iris set screw.

    > Note: This procedure simulates the amount of light that should be returned to the transceiver during clear stack conditions.

41. Allow three or thirteen minutes (depending upon the use of an averaging curcuit) for the tranceiver meter to display a stable reading and for the chart log to record the opacity value.

42. Record the time at the end of the waiting period on blank 22.

4.3.2 Insert Low Range Filter

43. Insert the low range neutral density filter into the audit device.

44. Wait for three or twelve minutes (depending upon the use of an averaging curcuit) for the chart recorder to log the opacity value.

45. Record the time at the end of the waiting period on blank 23.

46. Record the low range filter opacity value on blank 24 and serial number on blank 25.

4.3.3 Insert Mid range Filter

47. Remove the low range filter from the audit device.

48. Verify that the reading displayed on the transceiver meter returns to 0% opacity.

> Note: If the reading is not 0% opacity, the calibration check should be started over (i.e., return to Section 4.3.1).

49. Insert the mid range neutral density filter and repeat the procedures in Section 4.3.2.

50. Record the time, filter opacity value, and filter serial number on blanks 26, 27, and 28, respectively.

4.3.4 Insert High Range Filter

51. Repeat the procedures in Section 4.3.3 for the high range filter.

52. Record the time, filter opacity value, and filter serial number on blanks 29, 30, and 31, respectively.

4.3.5 Monitor Response Repeatability

53. Repeat the procedures in Sections 4.3.2, 4.3.3, and 4.3.4, until a total of five opacity readings is obtained for each neutral density filter.

54. Record the time for each test on blanks 32 through 43.

55. Once the calibration check is completed, remove the audit device.

4.4 PERFORMANCE AUDIT DATA RETRIEVAL

56. Return to the chart recorder.

57. Mark the time of day on the chart recorder.

58. Retrieve the opacity data found on the chart recorder.

Note: If the monitoring system has a control unit, skip to Section 4.4.3; if there is no control unit, continue with the next step.

4.4.1 Retrieve Internal Zero Response

Note: Perform this step if the monitoring system is not equipped with a control unit.

59. Locate the opacity reading corresponding to the time stated on blank 15.

60. Record the chart recorder opacity reading on blank 44.

4.4.2 Retrieve Internal Span Response

Note: Perform this step if the monitoring system is not equipped with a control unit.

61. Locate the opacity reading corresponding to the time on blank 17.

62. Record this chart recorder opacity reading on blank 45.

4.4.3 Retrieve Retroreflector Window Check Data

63. Locate the chart recorder opacity reading immediatley before the stated time on blank 20.

64. Record the opacity reading on blank 46.

65. Locate the opacity reading recorded after the appropriate time interval (three or thirteen minutes) from the time on blank 20.

66. Record the opacity reading on blank 47.

4.4.4 Retrieve Transceiver Window Check Data

67. Perform the same operation as described in Section 4.4.3 for the stated time on blank 21.

68. Record the opacity readings on blanks 48 and 49.

4.4.5 Retrieve Audit Device Installation Data

69. Locate the opacity reading immediately after the stated time on blank 22.

70. Record the opacity value on blank 50.

4.4.6 Retrieve Low Range Filter Data

71. Locate the opacity reading immediately after the stated time on blank 23.

72. Record the opacity value on blank 51.

4.4.7 Retrieve Mid range Filter Data

73. Locate the opacity reading immediately after the stated time on blank 26.

74. Record the opacity value on blank 52.

4.4.8 Retrieve High Range Filter Data

75. Locate the opacity reading immediately after the stated time on blank 29.

76. Record the opacity value on blank 53.

4.4.9 Retrieve Monitor Response Repeatability Data

77. Locate the opacity readings corresponding to the times stated on blanks 32 through 43.

78. Record the opacity values on blanks 54 through 65, respectively.

4.5 ANALYSIS OF PERFORMANCE AUDIT DATA

This section addresses the analysis of the performance audit data. Specific criteria for the different monitor checks are stated to provide a means to determine what areas of the monitoring system are performing correctly. The areas which are not within the stated specifications should be addressed and corrected.

The following analyses are not a complete listing of all of the problems that may affect the monitor accuracy; however, they do address the most frequent problems. These analyses will normally provide sufficient information to assess the accuracy of the monitor data and to indicate the deficiencies within the monitoring system.

4.5.1 True Assessment of Opacity Monitor Performance

A true assessment of the opacity monitor performance could be determined if clear stack conditions were present or if the source allowed the on-stack monitoring components to be removed from the stack and tested in a dust free environment (the same on-stack alignment and pathlength must be achieved). These two situations are not normally possible. Therefore, the following performance audit analyses are necessary to ascertain the specific problem areas within the monitoring system. These analyses provide a qualitative and quantitative assessment of opacity monitor performance.

4.5.2 Stack Exit Correlation

The pathlength correction error on blank 66 should be within ± 2%. This error exponentially affects the opacity readings and the error in the opacity readings may be greater than or less than the stack exit correction error, depending upon the opacity measured. The most common error in computing the optical pathlength ratio is the use of the flange-to-flange distance, rather than the stack/duct inside diameter. (The STR is factory-set and the user should not attempt adjustments without consulting the manufacturer.)

4.5.3 Control Panel or Transceiver Meter Correction Factor

The accuracy of the control panel meter or transceiver meter is determined by comparing the appropriate meter readings to the specified chopper span value. (It is not necessary to determine the correction factor for the transceiver meter if a control panel meter is present.) The errors in the control panel meter or transceiver meter should not affect the opacity data reported by the monitoring system, unless the control panel or transceiver meter is used to adjust the zero and span functions. The correction factor associated with the control panel meter or transceiver meter is found on blank 67 or 68, respectively. Even though it is not essential that the control panel or transceiver meter be accurate, the source should adjust the appropriate meter so that the correction factor falls within a range of 0.98 to 1.02. Since the control panel meter or transceiver meter error is determined by using the span portion of the chopper, any change in the chopper will result in an incorrect assessment of the meter error. The chopper span value may change due to replacement of the chopper, exposure to stack gases, or excessive dust accumulation on the chopper. Each time the monitor is thoroughly calibrated, the chopper span value should be renamed. The newest chopper span value should be used in the applicable analyses. A meter error of greater than 10% indicates a different monitor problem which should become apparent once the audit has been completed.

4.5.4 Internal Zero Offset and Span Error Calculation

The internal zero and span opacity responses on the chart recorder (blank 11 or blank 44) and (blank 69 or 70) should agree within ± 2% opacity with the manufacturer's specified values.

The internal zero and span functions will not indicate the anticipated opacity values for several reasons: (1) a chart recorder offset, (2) excessive dust accumulation on the transceiver optical surfaces, (3) a change in the actual value for the internal zero and span functions, and/or (4) electronic drift. A chart recorder offset will introduce an error of the same sign (positive or negative) and magnitude for both functions; the reported effluent opacity data will be offset (in error) in the same manner. Optical surface dust accumulation will be indicated by an activated fault lamp and/or during optical surface cleaning. A change in the actual values for the zero and span functions is apparent when a properly calibrated monitor does not accurately respond to the internal functions. If inaccurate zero and span responses cannot be shown to be due to the above reasons, the errors are probably due to electronic drift of the monitor.

4.5.5 Transmissometer Dust Accumulation Analysis

The opacity of the transceiver optical surface (blank 71a) and the opacity of the retroreflector optical surface (blank 71b) are combined to determine the total dust accumulation on the monitor's exposed optical surfaces. The opacity of the optical surfaces (blank 71c) should be $\leq$ 4% Op. A dust accumulation value of more than 4% opacity indicates that the airflow of the purge system and/or that the cleaning frequency of the optical surfaces are inadequate. When determining the retroreflector optical surface dust accumulation, the auditor should note whether the stack opacity is fairly stable (within ± 1% opacity) before and after the cleaning of the optical surface.

4.5.6 Calibration Check Analysis Calculation

To compare the chart recorder opacity responses to the opacity values of the neutral density filters, the filter values have to be corrected to stack exit conditions according to the equations on the audit data sheets (i.e., analysis Step E). The calculations are based on the assumption that the audit device produced a zero response on the chart recorder (i.e., value found on blank 50 is 0% Op). If this is not the case, the expected monitor responses to the audit filters (blanks 72 through 74) must be corrected again to account for this zero offset as follows:

$$Op_{adj} = [1 - (1 - \frac{Op_{ftr}}{100})(1 - \frac{Op_{zero}}{100})]$$

where:

Op_{adj} = Correct monitor response

Op_{ftr} = filter opacity, corrected to stack exit conditions

Op_{zero} = audit device zero offset (monitor opacity response to audit device without filter)

The calibration errors for the three audit filters (blanks 102, 103, and 104) should be $\leq$ 3% opacity.

Biases in the monitor responses to the audit filters are due to misadjustment of the zero and span functions or to calibration of the monitor with neutral density filters that had not been corrected by the monitor's optical pathlength correlation factor. If the zero and span are not within the proper range, the calibration check data will often be biased in the same direction as the zero and span errors. Even if the zero and span errors are within the proper ranges, the monitor may still not be electronically aligned (i.e., the monitor should be adjusted to indicate 0% opacity during clear stack conditions). If the monitor is calibrated using neutral density filters (usually off-stack) without applying the optical pathlength correction factor to the filters, the monitor responses will agree with the audit filters before they have been corrected to stack exit conditions. If this is the case, the monitor should be recalibrated according to the annual recalibration procedure.

5. ENVIRONMENTAL DATA CORPORATION, MODEL 1000A

OPACITY MONITORING SYSTEM

The EDC opacity monitor system consists of three major components: the transmissometer, the air-purging system, and the data acquisition system. The transmissometer component consists of an optical transmitter/receiver (transceiver) unit mounted on one side of a stack or duct and a retroreflector unit mounted on the opposite side. The transceiver unit contains a light source, a photodiode detector, and associated electronics, and the output from the transceiver is transmitted to a control unit or directly to a chart recorder. The chopper zero and span signals are monitored continuously and are electronically compensated through a gain control circuit so that the signals remain constant. Since the electronic gain compensation affects the zero and span signals and the measurement signal amplitude equally, all perturbations resulting from lamp intensity changes are theoretically cancelled out of the measurement signal.

The air-purging system serves a threefold purpose: (1) it provides an air window to keep exposed optical surfaces clean; (2) it protects the optical surfaces from condensation of moisture from stack gases; and (3) it minimizes thermal conduction from the stack to the instrument. A standard installation has one air-purging system for the transceiver unit and one for the retroreflector unit; each system has a blower that provides filtered air.

5.1 STACK EXIT OPACITY DETERMINATION

The opacity monitor measures the amount of light transmitted across the stack and returned from the retroreflector. The control unit calculates the optical density (OD) of the effluent stream, corrects the OD for pathlength differences between the measurement site and the stack exit, and converts the result to opacity. The relationship between stack exit opacity and optical density is described by the following equation:

$$Op_x = 1 - 10^{-(Lx/Lt)(OD)}$$

where: Op_x = stack exit opacity (%)

$\frac{L_x}{L_t}$ = optical pathlength ratio

L_x = stack exit diameter (ft)

L_t = measurement pathlength (ft)

OD = transmissometer optical density

5.1.1 Determine Accuracy of the Pathlength Ratio

1. Determine the transmissometer pathlength and stack exit diameter.

2. Record the stack exit diameter and the transmissometer pathlength on blanks 1 and 2, respectively, of the EDC 1000A Performance Audit Data Sheet in Appendix E.

   Note: If actual measurements are not practical, obtain the data from detailed plant blueprints or other available source information. The monitor pathlength is two times the length of the inside diameter of the stack at the monitor installation location.

3. Calculate the pathlength ratio (divide the value on blank 1 by value on blank 2).

4. Record the calculated pathlength ratio value on blank 3.

5. Obtain the preset pathlength ratio used by the monitor, and record the value on blank 4.

   Note: The pathlength ratio is preset by the manufacturer using information supplied by the source. The origin of the pathlength ratio value should be noted.

5.2 MONITORING SYSTEM CHECK

This section describes checks to gather the pertinent operating parameters necessary to ascertain whether the monitoring system is functioning properly. Since the EDC 1000A does not have a control unit, only Section 5.2.1 is performed in the control room. The test procedures described in Sections 5.2.2 through 5.2.4 are performed at the monitoring site to determine the status of the optical surfaces.

Many of the procedures call for a waiting period at the conclusion of an audit step to ensure that the strip chart recorder has had sufficient time to stabilize and record a steady response. For recorders with instantenous opacity readings, a waiting interval of three minutes should be sufficient. For recorders displaying six-minute averages, a waiting period of thirteen minutes is recommended. At a later time during the audit, the auditor retrieves the recorded opacity data corresponding to the specific audit steps.

Although the audit can be conducted by one person, two people can significantly reduce the waiting intervals and data retrieval times. The second person can stay with the strip chart recorder and record the necessary data as soon as a steady reading occurs.

5.2.1 Instrument Zero and Span Check

6. Mark the time of day on the chart recorder paper.

7. If the source has installed a switch to initiate the internal zero and span functions, initiate the zero and span cycle mode by pressing this CAL-INITIATE button.

   Note: The monitor will remain in the zero mode for approximately three minutes, after which the span mode will be automatically initiated.

8. Record the zero and span responses on blanks 5 and 6, respectively) that is displayed on the chart recorder.

   Note: The monitor will automatically return to normal operation. The cross-stack zero is simulated by using the zero mirror in the transceiver. The zero and span checks provide an indication of the status of the electronic alignment of the instrument. They do not, however, provide an indication of dirty window conditions, optical misalignment, or the true cross-stack zero.

9. Record the zero and span values on blanks 7 and 8, respectively, determined by the manufacturer.

   Note: The zero and span values are found in the Operation Manual.

5.2.2 Internal Calibration Check

10. If there is no CAL-INITIATE button in the control room, locate the MODE switch on the front of the transceiver, next to the input/output cable.

11. Move the MODE switch to the up position (ZERO).

12. Record the time of day on blank 9.

13. Allow the monitor to operate at least three minutes (thirteen minutes if the monitoring system processes the data through a six-minute averaging circuit) for the chart recorder to log the zero response.

14. Move the MODE switch to the down position (SPAN).

15. Record the time of day on blank 10.

16. Wait another three or thirteen minutes (depending upon the use of an averaging circuit) for the chart recorder to log the span response.

17. Return the MODE switch to the center position (OPERATE).

5.2.3 Transceiver Window Check

18. Allow the monitor to operate at least three or thirteen minutes (depending upon the use of an averaging circuit).

19. Clean the measurement window of the transceiver.

20. Record the time of cleaning on blank 11.

21. Wait an additional three or thirteen minutes (depending upon the use of an averaging circuit).

> Note: The transceiver window is mounted in a slide at the front of the transceiver. The slide pulls up approximately six inches to allow cleaning of the transceiver window; do not remove the slide completely.

5.2.4 Retroreflector Window Check

22. Repeat the procedures described in Section 5.2.3, except clean the retroreflector optical surface in lieu of the transceiver measurement window.

23. Record the time of cleaning on blank 12.

5.3 CALIBRATION CHECK

Normally, the calibration check (incremental) is performed by substituting neutral density slides in place of the transceiver measurement window. This check should be performed only when the stack opacity is fairly steady. The calibration check provides a determination of the linearity of the instrument response and utilizes all of the components of the measurement system. This calibration check does not provide a test of the actual instrument zero.

Only under clear stack conditions will the calibration check provide a check of the actual instrument zero and calibration status. A true calibration check can also be obtained by removing the on-stack components and setting them up in the control room, making sure that the on-stack pathlength and alignment are duplicated.

5.3.1 Insert Low Range Filter

24. Wait three or thirteen minutes (depending upon the use of an averaging circuit).

25. Record the time at the end of the waiting period on blank 13.

26. Insert the low range neutral density filter slide into the retroreflector.

27. Wait another three or thirteen minutes.

28. Record the time at the end of this second waiting period on blank 14.

29. Remove the low range audit slide.

30. Wait another three or thirteen minutes.

31. During this waiting period, record the audit filter's opacity value on blank 15 and serial number on blank 16.

32. Record the time at the end of this third waiting period on blank 17.

5.3.2 Insert Mid range Filter

33. Insert the mid range audit filter.

34. Wait three or thirteen minutes (depending upon the use of an averaging circuit).

35. Record the time at end of the waiting period on blank 18.

36. Remove the mid range slide.

37. Wait another three or thirteen minutes.

38. During this second waiting period, record the audit filter's opacity value on blank 19 and serial number blank 20.

39. Record the time at the end of the second waiting period on blank 21.

5.3.3 Insert High Range Filter

40. Insert the high range audit slide.

41. Wait three or thirteen minutes (depending upon the use of an averaging circuit).

42. Record the time at end of the waiting period on blank 22.

43. Remove the audit slide.

44. Record the slide's opacity value on blank 23 and serial number on blank 24.

5.3.4 Monitor Response Repeatability

45. Repeat the procedures in Sections 5.3.1, 5.3.2, and 5.3.3 until a total of five opacity readings is obtained for each neutral density slide.

46. Record the approximate times for each test on blanks 25 through 48.

47. After removing the high range audit slide for the last time, wait an additional three or thirteen minutes.

48. Record the time at the end of this final waiting period on blank 49.

5.4 PERFORMANCE AUDIT DATA RETRIEVAL

49. Return to the chart recorder location, and mark the time of day on the chart recorder paper.

50. Retrieve the opacity data found on the chart recorder.

5.4.1 Retrieve Internal Span Data

51. If the internal zero and span modes were initiated at the transceiver, locate the opacity reading corresponding to the time on blank 9.

52. Record the zero response on blank 50.

53. Locate the opacity reading corresponding to the time on blank 10.

54. Record the span response on blank 51.

5.4.2 Retrieve Transceiver Window Check Data

55. Locate the opacity reading immediatley before the stated time on blank 11

56. Record the opacity reading on blank 52.

57. Locate the opacity reading recorded after the appropriate time interval (three or thirteen minutes) from the time on blank 11.

58. Record the opacity reading on blank 53.

5.4.3 Retrieve Retroreflector Window Check Data

59. Perform the same operation as described in Section 5.4.2 for the stated time on blank 12.

60. Record the opacity readings on blanks 54 and 55.

5.4.4 Retrieve Low Range Filter Data

61. Locate the opacity reading immediately after the stated times on blanks 13, 14, and 17.

62. Record the opacity values on blanks 56, 57, and 58, respectively.

5.4.5 Retrieve Mid Range Filter Data

63. Locate the opacity reading immediately after the stated times on blanks 18 and 21.

64. Record the opacity values on blanks 59 and 60.

5.4.6 Retrieve High Range Filter Data

65. Locate the opacity reading immediately after the stated time on blank 22.

66. Record the opacity value on blank 61.

5.4.7 Retrieve Monitor Response Repeatability Data

67. Locate the opacity readings (as in Sections 5.4.4, 5.4.5 and 5.4.6) corresponding to the times stated on blanks 25 through 49.

68. Record the opacity values on blanks 62 through 85, respectively.

5.5 ANALYSIS OF PERFORMANCE AUDIT DATA

This section addresses the analysis of the performance audit data. Specific criteria for the different monitor checks are stated to provide a means to determine which areas of the monitoring system are performing correctly. The areas that are not within the stated specifications should be addressed and corrected. The following analyses are not a complete listing of all of the problems that may affect the monitor accuracy; however, they do address the most frequently encountered problems. These analyses will normally provide the auditor with sufficient information to assess the accuracy of the monitor data and to identify deficiencies in the operation and maintenance practices of the monitoring system.

5.5.1 True Assessment of Opacity Monitor Performance

A true assessment of the opacity monitor performance could be determined if clear stack conditions were present or if the source allowed the on-stack monitoring components to be removed from the stack and tested in a dust-free environment
(the same on-stack alignment and pathlength must be achieved). Normally these two situations are not possible; therefore, the following performance audit analyses are necessary to ascertain the specific problem areas within the monitoring system and to provide qualitative and quantitative assessment of the performance of the opacity monitor.

5.5.2 Stack Exit Correlation

The pathlength correction error on blank 87 should be within ±2%. This error exponentially affects the opacity readings. The error in the opacity readings may be greater than or less than the stack exit correction error, depending upon the opacity measured. The most common error in computing the optical pathlength ratio is the use of the flange-to-flange distance rather than the stack/duct inside diameter. (The pathlength ratio is factory-set and the user should not attempt adjustments without consulting the manufacturer.)

5.5.3 Internal Zero and Span Error Calculation

The internal zero and span opacity responses on the chart recorder (blank 88 or 90) and (blank 89 or 91), respectively should agree within ± 2% opacity with the manufacturer's specified values.

The internal zero and span errors may be caused by electronic drift, a chart recorder offset, excessive dust accumulation on the transceiver optical surfaces, and/or a change in the zero filter value. Electronic drift results from inadequate electrical alignment maintenance practices and may result in zero and span errors of different directions and magnitude. A recorder offset will cause zero and span errors in the same direction and magnitude and will offset the opacity data in the same manner. Excessive dust accumulation on the transceiver optical surfaces will result in positive zero and span errors having the same magnitude, and the opacity data also will be biased in the same manner. A change in the span filter opacity occurs because of either ageing or replacement of the filter (i.e., the new span filter probably will have a different opacity value).

5.5.4 Transmissometer Dust Accumulation Analysis

The opacity of the transceiver optical surface (blank 92a) and the opacity of the retroreflector optical surface (blank 92b) are combined to determine the total dust accumulation on the monitor's exposed optical surfaces. The total opacity of the optical surfaces (blank 92c) should be ≤ 4% Op. A dust accumulation value of more than 4% opacity indicates that the airflow of the purge system is inadequate and/or the cleaning frequency of the optical surfaces is inadequate. When determining the optical surface dust accumulation, the auditor should note whether the stack opacity is fairly stable (within ± 1% opacity) before and after the cleaning of the optical surfaces.

5.5.5 Calibration Check Analysis Calculation

Since the stack opacity is measured in conjunction with the audit slides, the chart recorder displays the combined effect. To compare the chart recorder opacity responses with the opacity values of the neutral density slides, the slide values (corrected to stack exit conditions, analysis Step E) have to be combined with the stack opacity (analysis Steps F, H, and J). The stack opacity during the combined measurement is assumed to equal the average of the measured stack opacity before and after the insertion of an audit slide. The calibration errors for the three audit slides (blanks 138, 139, and 140) should be ≤ 3% opacity.

Biases in the monitor responses to the audit filters are often due to misadjustment of the zero and span functions or to calibration of the monitor with neutral density filters that had not been corrected by the monitor's optical pathlength correlation factor. Zero and span errors will cause the calibration check data to be biased in the same direction. Even if the zero and span errors are within the proper ranges, the monitor may still not be electronically aligned. If the monitor is calibrated using neutral density filters (usually off-stack) without applying the optical pathlength correction factor to the filters, the monitor responses will agree with the audit filters before they have been corrected to stack exit conditions and the monitor should be recalibrated.

6. THERMO ELECTRON CORPORATION,

ENVIRONMENTAL DATA D-R280 AV OPACITY MONITORING SYSTEM

The Thermo Electron opacity monitor system consists of three major components: the transmissometer and on-stack control unit, the air-purging system, and the remote control unit and data acquisition equipment. The transmissometer component consists of an optical transmitter/receiver (transceiver) unit mounted on one side of a stack or duct and a retroreflector unit mounted on the opposite side. The transceiver contains a light source, a photodiode detector, and their associated electronics. The on-stack control unit provides a readout of the milliamp signal from the transceiver and initiates the internal zero and span checks. Figure 6-1 illustrates the general arrangement of the transmissometer transceiver, on-stack control unit, and retroreflector units on the stack. The transceiver uses a single-lamp, single-detector system and a chopper to determine stack opacity. The chopper, located inside the optical compartment, modulates the light beam to eliminate interference from ambient light.

The air-purging system serves a threefold purpose: (1) it provides an air window to keep exposed optical surfaces clean; (2) it protects the optical surfaces from condensation of moisture from stack gases; and (3) it minimizes thermal conduction from the stack to the instrument. A standard installation has one air-purging system for both the transceiver and the retroreflector unit, and one blower that provides filtered air.

The remote control unit (Figure 6-2) converts the nonlinear transmittance output from the transceiver (a milliamp signal) into linear opacity measurements. It also corrects the opacity measurement according to the ratio of the stack exit diameter to the transmissometer pathlength. (Thermo Electron now markets a "new" opacity monitoring system - the D-R281 AV; this system is the same as the D-R280, except that the remote control unit also provides an optical density readout.)

6.1 STACK EXIT OPACITY DETERMINATION

The opacity monitor measures the amount of light transmitted across the stack and returned from the retroreflector. The remote control unit then calculates the optical density (OD) of the effluent stream at the monitor location, corrects for pathlength differences between the measurement site and the stack exit, and converts the OD to opacity. The relationship between stack exit opacity and optical density is described by the following equation:

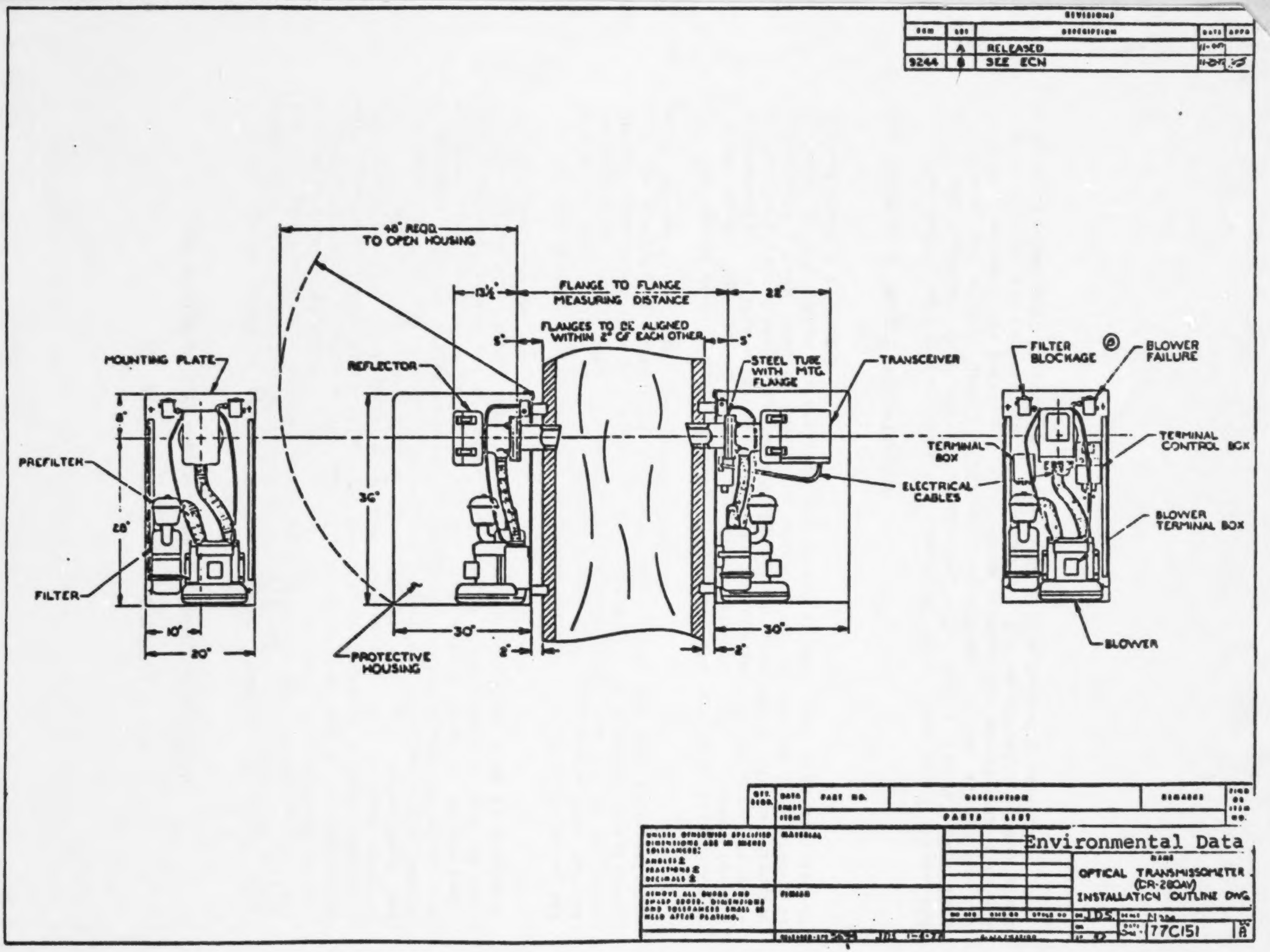
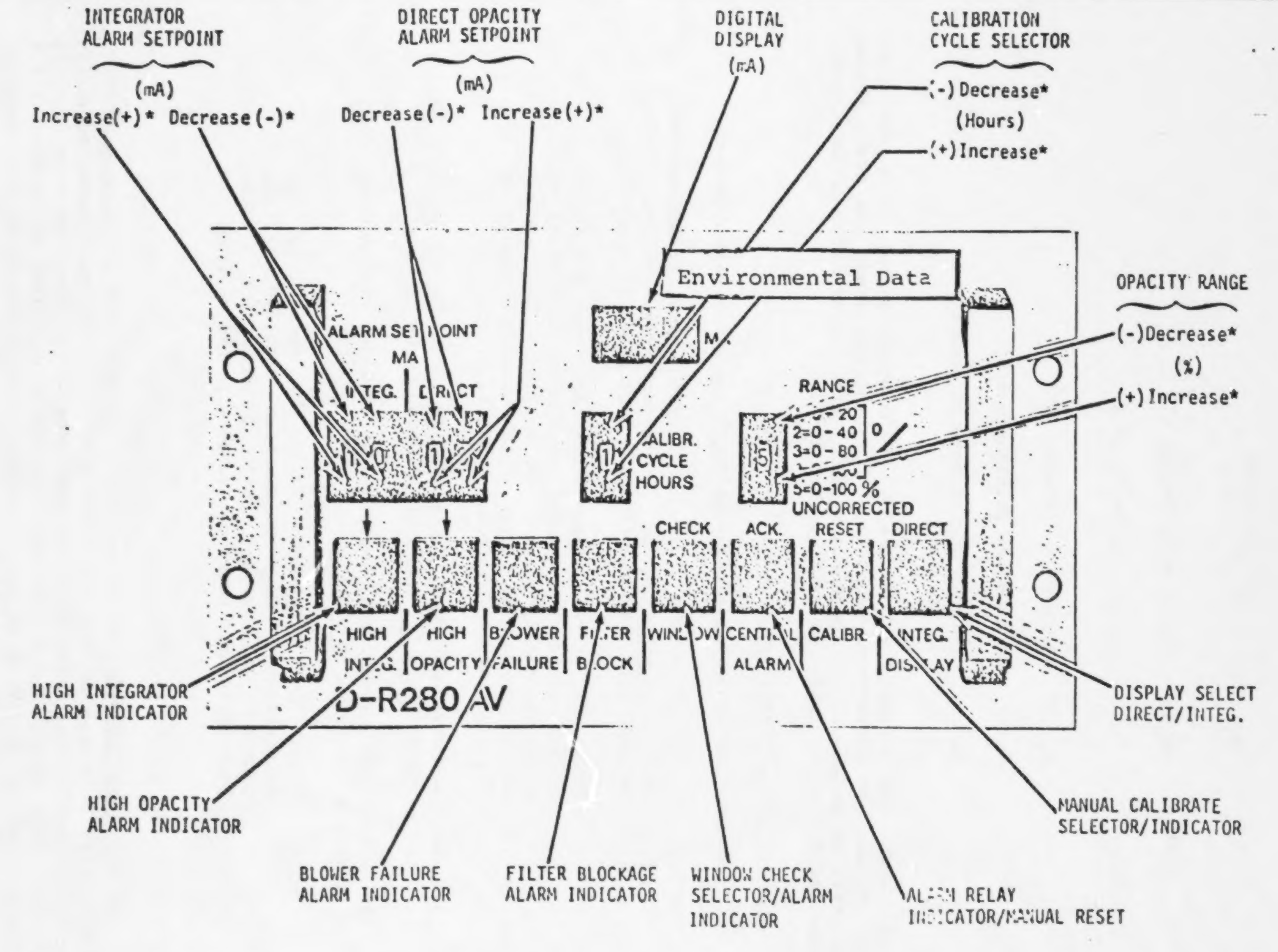

REVISIONS
A RELEASED
9244 B SEE ECN
40" REQD. TO OPEN HOUSING
FLANGE TO FLANGE MEASURING DISTANCE
FLANGES TO BE ALIGNED WITHIN 2° OF EACH OTHER
13½"
28"
5"
5"
MOUNTING PLATE
PREFILTER
FILTER
8"
20"
10"
20"
REFLECTOR
36"
30"
2"
PROTECTIVE HOUSING
STEEL TUBE WITH MTG. FLANGE
TRANSCEIVER
30"
2"
FILTER BLOCKAGE
BLOWER FAILURE
TERMINAL BOX
TERMINAL CONTROL BOX
ELECTRICAL CABLES
BLOWER TERMINAL BOX
BLOWER
PARTS LIST
Environmental Data
OPTICAL TRANSMISSOMETER (DR-280AV) INSTALLATION OUTLINE DWG.
77C151
B

Figure 6-1. Thermo Electron D-R280 AV Transmissometer General Arrangement


INTEGRATOR ALARM SETPOINT
(mA)
Increase(+)* Decrease(-)*
DIRECT OPACITY ALARM SETPOINT
(mA)
Decrease(-)* Increase(+)*
DIGITAL DISPLAY
(mA)
CALIBRATION CYCLE SELECTOR
(-) Decrease*
(Hours)
(+) Increase*
Environmental Data
OPACITY RANGE
(-)Decrease*
(%)
(+) Increase*
ALARM SETPOINT
MA
INTEG.
DIRECT
CALIBR. CYCLE HOURS
RANGE
2=0-40
3=0-80
5=0-100 %
UNCORRECTED
CHECK
ACK.
RESET
DIRECT
HIGH INTEG.
HIGH OPACITY
BLOWER FAILURE
FILTER BLOCK
WINDOW
CENTRAL ALARM
CALIBR.
INTEG. DISPLAY
D-R280 AV
HIGH INTEGRATOR ALARM INDICATOR
HIGH OPACITY ALARM INDICATOR
BLOWER FAILURE ALARM INDICATOR
FILTER BLOCKAGE ALARM INDICATOR
WINDOW CHECK SELECTOR/ALARM INDICATOR
ALARM RELAY INDICATOR/MANUAL RESET
MANUAL CALIBRATE SELECTOR/INDICATOR
DISPLAY SELECT DIRECT/INTEG.
P11153

* PUSH-BUTTON DECADE SWITCH.

Figure 6-2. Thermo Electron D-R280 Control Panel

$$Op_x = 1 - 10^{-(L_x/L_t)(OD)}$$

where: Op_x = stack exit opacity (%)

$\frac{L_x}{L_t}$ = optical pathlength ratio

L_x = stack exit diameter (ft)

L_t = measurement pathlength (ft)

OD = transmissometer optical density

Even though the Thermo Electron D-R280 AV transmissometer is a dual-pass monitor, use the measurement pathlength (L_t), not two times the stack inside diameter, to calculate the pathlength ratio (the factor of two is already accounted for by the control unit's electronics).

6.1.1 Stack Exit Correlation Error

1. Measure the transmissometer pathlength and stack exit diameter.
2. Record the stack exit inside diameter and transmissometer pathlength on blanks 1 and 2, respectively, of the Thermo Electron D-R280 AV Performance Audit Data Sheet in Appendix F.

   Note: If actual measurements are not practical, obtain the data from detailed plant blueprints or other available source information. The monitor pathlength is the length of the inside diameter of the stack at the monitor installation location.

3. Calculate the pathlength ratio (divide the value on blank 1 by the value on blank 2), and record the value on blank 3.
4. Obtain the preset pathlength ratio used by the monitor, and record the value on blank 4.

   Note: The pathlength ratio is preset by the manufacturer using information supplied by the source. This preset ratio is recorded on the instrument data sheet delivered with the monitor.

6.2 MONITORING SYSTEM CHECK

This section describes checks to gather the pertinent operating parameters necessary to ascertain whether the monitoring system is functioning properly. The remote control unit parameters are addressed within the procedures found in Sections 6.2.1 through 6.2.3. The test procedures described in Sections 6.2.4 through 6.2.6 are performed at the monitoring site to determine the status of the optical surfaces and the transmissometer alignment.

Many of the procedures call for a waiting period at the conclusion of an audit step to ensure that the strip chart recorder has had sufficient time to stabilize and record a steady response. If the recorder displays instantaneous opacity readings, a waiting interval of three minutes should be sufficient. If the recorder displays only six-minute averages, a waiting period of thirteen minutes is recommended. At a later time during the audit, the auditor retrieves the recorded opacity data corresponding to the specific audit steps.

Although the audit can be conducted by one person, a second person can significantly reduce the waiting intervals by staying with the strip chart recorder and recording the necessary data as soon as a steady reading occurs.

6.2.1 Fault Indicators Check

The following list describes the fault lamps that are found on a Thermo Electron transmissometer remote control unit front panel. Unless otherwise noted, the audit analyses can continue with illuminated fault lamps, provided that the source has been informed of the fault conditions.

5. Record the status (ON or OFF) of the BLOWER FAILURE fault lamp on blank 5.

   Note: An illuminated BLOWER FAILURE fault lamp indicates no power to the transceiver or to purge air blowers. If this condition exists, the audit should be halted and the source should be notified immediately, since the monitor may be damaged by the stack gases.

6. Record the status (ON or OFF) of the FILTER BLOCK fault lamp on blank 6.

   Note: The FILTER BLOCK fault lamp indicates inadequate purge airflow to maintain optical surface cleanliness. If the FILTER BLOCK fault lamp is illuminated, the filter element cleaning the purge air is dirty and restricting the airflow; the filter needs to be cleaned. Plant personnel should be informed if this lamp is on so corrective measures can be initiated at the conclusion of the audit. (This fault lamp is not an indicator of dirt on the measurement window.)

7. Record the status (ON or OFF) of the WINDOW fault lamp on blank 7.

   Note: An illuminated WINDOW fault lamp indicates that the opacity of the measurement window exceeds the preset limit of 3% opacity. When the dirty window limit has been exceeded, the opacity data may be biased. This lamp indicates a need to clean the dirty window surfaces; however, it only monitors the transceiver window.

6.2.2 Instrument Zero and Span Check

8. Check the opacity range switch indicator located on the remote control panel above the ACK/CENTRAL ALARM lamp (see Figure 6-2) to determine the range selected.

9. Record the range on blank 8.

10. Set the opacity range switch to range "4".

11. Initiate the calibration cycle by pushing the CALIBR button on the control panel.

    Note: The green CALIBR lamp will light, and the monitor will automatically cycle through the internal and external zero and span modes.

12. Record the internal zero milliamp value on blank 9 displayed on the control panel.

    Note: The internal zero simply checks the reference beam inside the transceiver and provides a check of the electronic alignment of the instrument. After two minutes in the internal zero mode, the monitor will automatically switch to the external zero mode.

13. Record the external zero value displayed on the panel meter on blank 10a and the zero value displayed on the chart recorder on Blank 10b.

    Note: The external zero is simulated by using the zero retroreflector. The external zero value displayed on the panel meter provides an indication of the amount of dust on the transceiver measurement window. The external zero value displayed on the chart recorder is the monitor zero after compensation for dust accumulation on the transceiver optics. Neither the panel meter nor strip chart recorder external zero values provide an indication of dirty window conditions at the measurement retroreflector, of optical misalignment, or of the true cross-stack zero. After two minutes in the external zero mode, the monitor cycles into the internal span function; the milliamp signal on the control unit corresponds to the span opacity value.

14. Record the span milliamp value on blank 11 displayed on the control panel meter and the span percent opacity value on blank 12 displayed on the chart recorder.

    Note: The transceiver automatically spans the monitor using the span filter and the external zero retroreflector. The span measurement provides another check of the electrical alignment and the linearitv of the transmissometer response to opacity.

After the completion of the zero and span calibration cycle, the monitor will automatically return to the stack opacity measurement mode.

15. Mark the time of day on the chart recorder.

6.2.3 Span Value Check

16. Record the span filter milliamp value on blank 13 and opacity value on blank 14 supplied by the manufacturer.

Note: The span values are recorded on the Instrument Data Sheet supplied with the monitor. If the manufacturer did not supply the source with the opacity value of the internal span, the following equation should be used to compute the span opacity value.

$$(\text{Blank } 14) = 6.25[(\text{Blank } 13) - 4.0]$$

6.2.4 Alignment Check

17. Determine the monitor alignment by looking through the bull's eye on the side of the transceiver (Figure 6-3).

18. Observe whether the images are centered on either side the cross hairs and record this information (YES or NO) on blank 15.

Note: There are two types of retroreflectors used for the monitor, and the resulting alignment images are different, as indicated in Figure 6-4. Instrument optical alignment has no effect on the internal checks of the instrument or the calibration error determination; however, if the instrument is misaligned, the opacity data will be biased high, since all the light transmitted to the retroreflector is not returned to the detector.

6.2.5 Retroreflector Window Check

19. Allow the monitor to operate at least three minutes (thirteen minutes if the monitoring system processes the data through a six-minute averaging circuit).

20. Clean the window of the measurement retroreflector.

21. Record the time of the measurement retroreflector window cleaning on blank 16.

22. Wait an additional three or thirteen minutes (depending upon the use of an averaging circuit) before proceeding to the next step.

6.2.6 Transceiver Window Check

23. Open the transceiver, clean the zero retroreflector and transceiver measurement window, and close the transceiver.

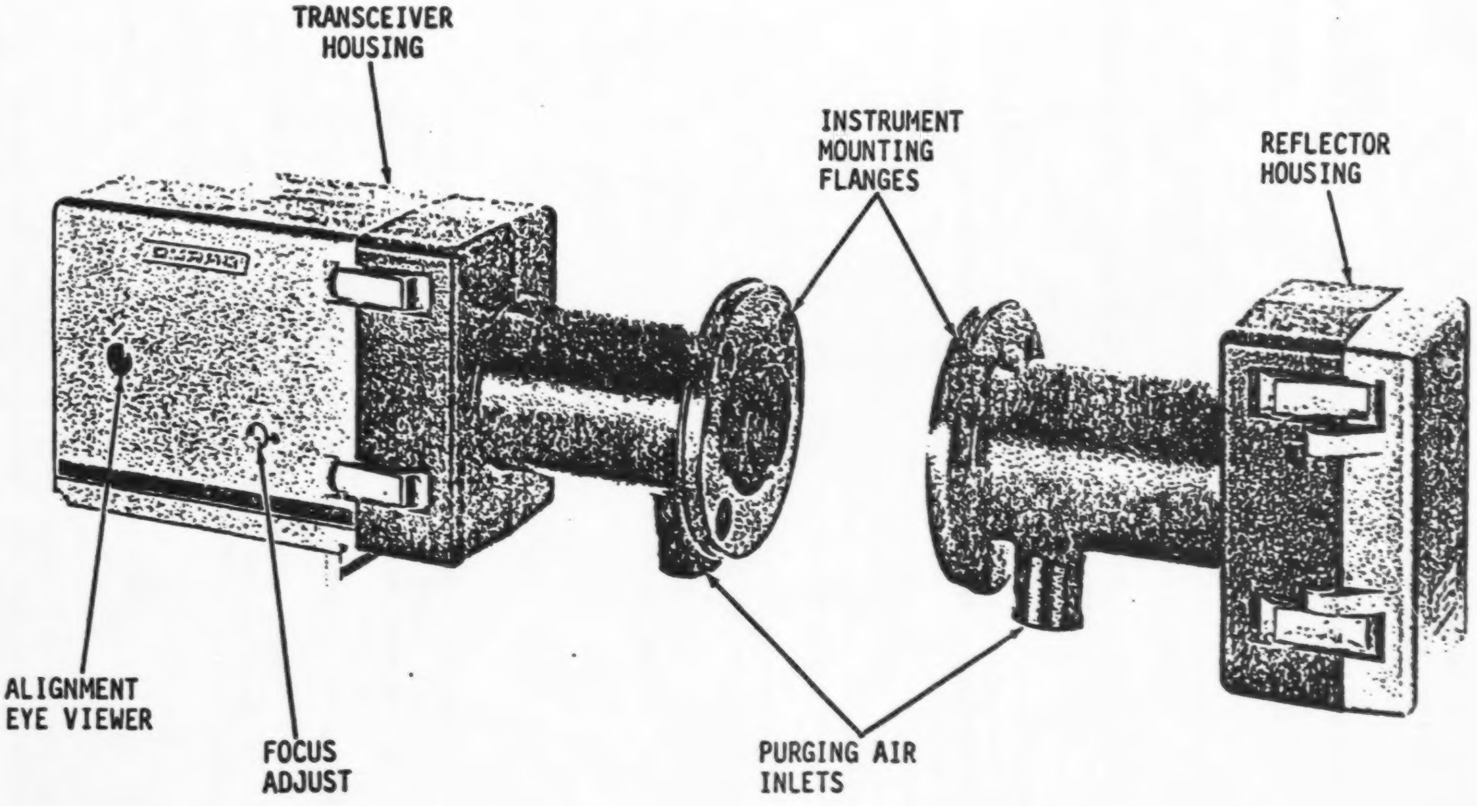

TRANSCEIVER HOUSING
INSTRUMENT MOUNTING FLANGES
REFLECTOR HOUSING
ALIGNMENT EYE VIEWER
FOCUS ADJUST
PURGING AIR INLETS

Figure 6-3. Thermo Electron D-R280 Transceiver

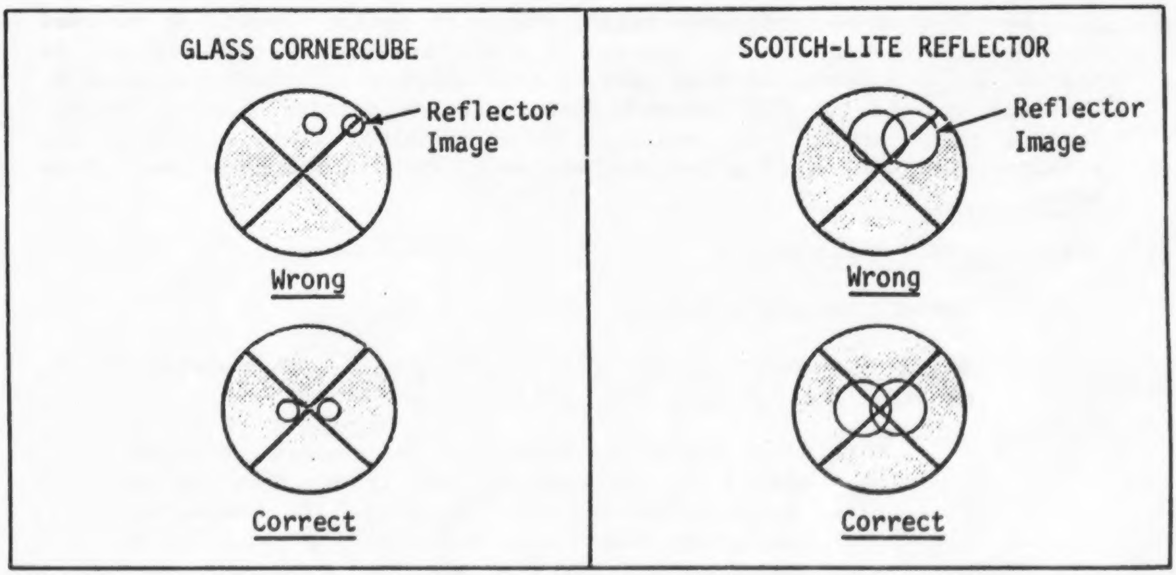

GLASS CORNERCUBE
Reflector Image
Wrong
Correct
SCOTCH-LITE REFLECTOR
Reflector Image
Wrong
Correct

Figure 6-4. Instrument Alignment Guide

24. Record the time of the transceiver optical surface cleaning on blank 17.

25. Wait an additional three or thirteen minutes (depending upon the use of an averaging circuit) before proceeding to the next step.

6.3 CALIBRATION CHECK

Normally, the calibration check is performed using a portable audit device with an adjustable retroreflector (iris) to simulate clear stack conditions. The audit device and neutral density filters can be used to determine the linearity of the instrument response free of interference from varying stack opacity. The calibration check does not determine the actual instrument zero or the status of the on-stack alignment.

If clear stack conditions exist, the audit device should not be used for the calibration check; instead the calibration filters should be placed in the measurement beam path. A true calibration check can also be obtained by removing the on-stack components and setting them up in the control room, making sure that the proper pathlength and alignment are attained, and then placing the calibration filters in the measurement beam path.

6.3.1 Install Audit Device

26. Install the audit device.

27. Adjust the audit device iris to produce a 4 mA reading on the on-stack control unit panel meter (Figure 6-5).

> Note: This procedure simulates the amount of light that should be returned to the transceiver during clear stack conditions. If two people are conducting the audit, use the chart recorder instead of the stack meter to zero the instrument.

28. Allow three or thirteen minutes (depending upon the use of an averaging circuit) for the tranceiver meter to display a stable reading and for the chart recorder to log the opacity value.

29. Record the time at the end of the waiting period on blank 18.

6.3.2 Insert Low Range Filter

30. Insert the low range neutral density filter.

31. Wait for three or thirteen minutes (depending upon the use of an averaging circuit).

32. Record the time at the end of the waiting period on blank 19.

33. Record the low range filter opacity value on blank 20 and the serial number on blank 21.

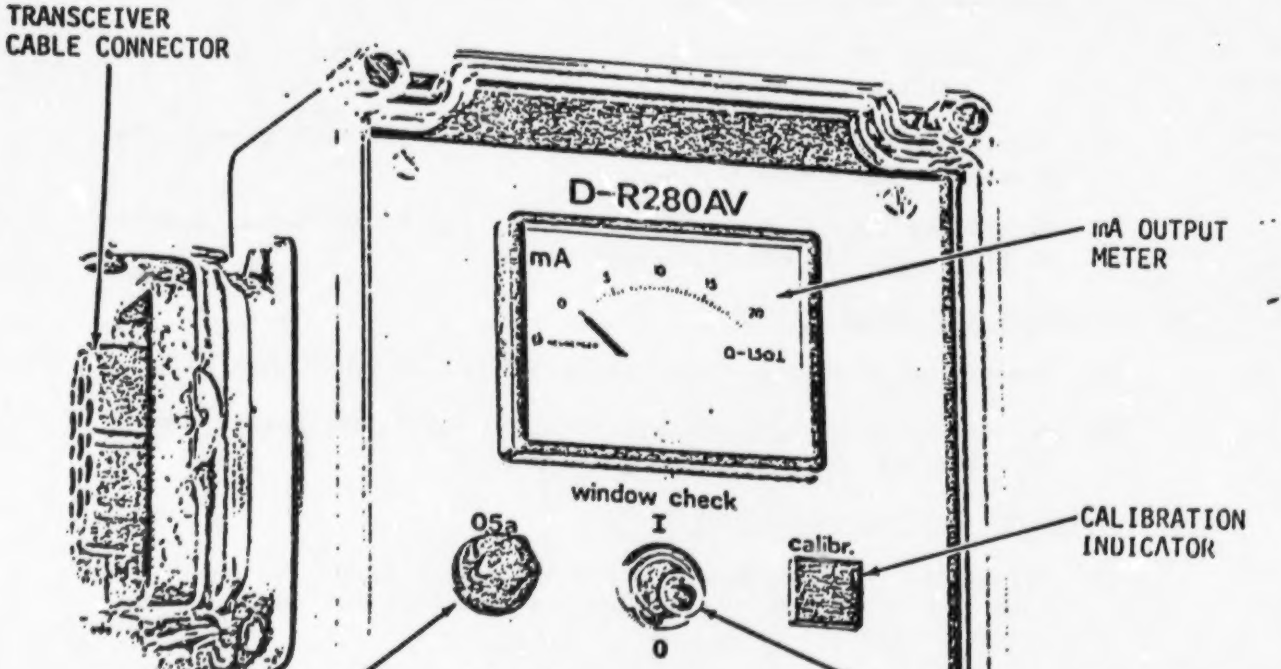

TRANSCEIVER CABLE CONNECTOR
D-R280AV
mA
0
5
10
15
20
mA OUTPUT METER
window check
05a
I
0
calibr.
CALIBRATION INDICATOR
power
115v60hz
remote panel
CHECK/OUTPUT METER SWITCH
POWER FUSE
1
2
3
4
5
6
7
8
9
10
11
JUNCTION TERMINAL

Figure 6-5. On-Stack Control Unit

6.3.3 Insert Mid range Filter

34. Remove the low range filter from the audit device.

35. Check to see if the reading displayed on the on-stack control unit meter returns to 4 mA.

    Note: If the reading is not 4 mA, reinitiate the calibration check.

36. Insert the mid range neutral density filter and repeat the procedures in Section 6.3.2.

37. Record the time, filter opacity value, and filter serial number on blanks 22, 23, and 24, respectively.

6.3.4 Insert High Range Filter

38. Repeat the procedures in Section 6.3.3 for the high range filter.

39. Record the time, filter opacity value, and filter serial number on blanks 25, 26, and 27, respectively.

6.3.5 Monitor Response Repeatability

40. Repeat the procedures in Sections 6.3.2, 6.3.3, and 6.3.4 until a total of five opacity readings is obtained for each neutral density filter.

41. Record the time for each test on blanks 28 through 39.

42. Remove the audit device once the calibration check is finished.

43. Return to the control room.

44. Change the opacity range switch back to its original position (blank 8), if it was changed for the audit.

6.4 PERFORMANCE AUDIT DATA RETRIEVAL

45. Return to the chart recorder location.

46. Mark the time of day on the chart recorder paper.

47. Retrieve the opacity data found on the chart recorder.

6.4.1 Retrieve Retroreflector Window Check Data

48. Locate the chart recorder opacity reading immediately before the stated time on blank 16.

49. Record the opacity reading on blank 40.

50. Locate the opacity reading recorded after the appropriate time interval (three or thirteen minutes) from the time on blank 16.

51. Record the opacity reading on blank 41.

6.4.2 Retrieve Transceiver Window Check Data

52. Perform the same operation as described in Section 6.4.1 for the stated time on blank 17.

53. Record the opacity readings on blanks 42 and 43.

6.4.3 Retrieve Audit Device Installation Data

54. Locate the opacity reading immediately after the stated time on blank 18.

55. Record the opacity value on blank 44.

6.4.4 Retrieve Low Range Filter Data

56. Locate the opacity reading immediately after the stated time on blank 19.

57. Record the opacity value on blank 45.

6.4.5 Retrieve Midrange Filter Data

58. Locate the opacity reading immediately after the stated time on blank 22.

59. Record the opacity value on blank 46.

6.4.6 Retrieve High Range Filter Data

60. Locate the opacity reading immediately after the stated time on blank 25.

61. Record the opacity value on blank 47.

6.4.7 Retrieve Monitor Response Repeatability Data

62. Locate the opacity readings corresponding to the times stated on blanks 28 through 39.

63. Record the opacity values on blanks 48 through 59. respectively.

6.5 ANALYSIS OF PERFORMANCE AUDIT DATA

This section addresses the analysis of the performance audit data. Specific criteria for the different monitor checks are stated to provide a means of determining which areas of the monitoring system are performing correctly. The areas that are not within the stated specifications should be addressed and corrected. The following analyses are not a complete listing of all of the problems that may affect monitor accuracy; however, they do address the most frequent problems. These analyses will normally provide sufficient information to assess the accuracy of the monitor data and to indicate the deficiencies within the monitoring system.

6.5.1 True Assessment of Opacity Monitor Performance

A true assessment of the opacity monitor performance could be determined if clear stack conditions were present or if the source allowed the on-stack monitoring components to be removed from the stack and tested in a dust free environment
(the same on-stack alignment and pathlength must be achieved). Normally these two situations are not possible. Therefore, the following performance audit analyses are necessary to qualitatively and quantitatively assess the performance of the transmissometer.

6.5.2 Stack Exit Correlation

The pathlength correction error (blank 60) should be within ± 2%. The error exponentially affects the opacity readings and the error in the opacity readings may be greater than or less than the stack exit correction error, depending upon the opacity measured. The most common error in computing the optical pathlength ratio is the use of the flange-to-flange distance rather than the stack/duct inside diameter. (The correction factor is factory-set, and the user should not attempt adjustments without consulting the manufacturer.)

6.5.3 Control Panel Meter Correction Factor

The accuracy of the remote control panel meter is determined by comparing the appropriate meter readings to the specified span filter value. The errors in the control panel meter should not affect the opacity data reported by the monitoring system, unless the control panel meter is used to adjust the zero and span functions. The correction factor associated with the control panel meter is found on blank 61. Even though it is not essential that the control panel meter be accurate, the source should adjust the meter so that the correction factor falls within a range of 0.98 to 1.02. Since the control panel meter error is determined by using the span filter, any change in the specified values for the span filter will cause an erroneous assessment of the control panel meter errors. The span filter value may change due to ageing, replacement, etc. Each time the monitor is thoroughly calibrated, the internal span filter should be renamed (new specified values); the latest values determined for the span filter should be used in all applicable analyses. A meter error of greater than 10% indicates a different monitor problem which should become apparent once the audit has been completed.

6.5.4 Zero and Span Error Analysis

The internal zero response on blank 9 should fall within a range of 3.7 mA to 4.3 mA. The external zero response on blank 10b (monitor zero after compensation for dust accumulation) and span response (on blank 62) should agree within ± 2% opacity with the manufacturer's specified values.

The internal zero and span errors may be caused by electronic drift, a chart recorder offset, excessive dust accumulation on the optical surfaces, and/or a change in the zero filter value. Electronic drift results from inadequate electrical alignment maintenance practices, and may result in the zero and span errors in different directions and magnitude. A recorder offset will cause zero and span errors in the same direction and magnitude and will offset the opacity data in the same manner. Excessive dust accumulation on the transceiver optical surface will result in positive zero and span errors, and will have the same magnitude; the opacity data also will be biased in the same manner. A change in the span filter opacity occurs because of either ageing or replacement of the filter (i.e., the new span filter probably will have a different opacity value).

6.5.5 Transmissometer Dust Accumulation Analysis

The opacity of the transceiver optical surface (blank 63) and the opacity of the retroreflector optical surface (blank 64) are combined to determine the total dust accumulation on the monitor's exposed optical surfaces. The opacity of the optical surfaces (blank 65) should be $\leq$ 4% opacity. A dust accumulation value of more than 4% opacity indicates that the airflow of the purge system is inadequate and/or the cleaning frequency of the optical surfaces is inadequate. When determining the optical surface dust accumulation, the auditor should note whether the stack opacity is fairly stable (within ± 1% opacity) before and after the cleaning of the optical surfaces.

The external zero displayed on the control unit panel meter is an indication of the dust deposition upon the zero retroreflector and transceiver measurement window, and thus, the external zero response (blank 10a), converted to % opacity, should equal the amount of dust found on the transceiver optics (blank 63). To convert the panel meter mA response to % opacity, use the following equation:

$$\text{Meter response in \% opacity} = 6.25[(\text{Blank 10a}) - (\text{Blank 9})]$$

If the monitor's internal zero response (blank 9) is within the recommended range (3.7 mA to 4.3 ma mA), the accuracy of the monitor's external zero function can be checked through the use of the dust accumulation analysis results. The external zero is an indication of the dust deposition upon the zero retroreflector and transceiver measurement window, and thus, the external zero response (blank 10) should equal the amount of dust found on the transceiver optics (blank 63).

6.5.6 Calibration Check Calculation

To compare the chart recorder opacity responses to the opacity values of the neutral density filters, the filter values must be corrected to stack exit conditions according to the equations on the audit data sheets (i.e., analysis Step E). The calculations are based on the assumption that the audit device produced a zero response on the chart recorder (i.e., value found on blank 44 is 0% Op). If this is not the case, the expected monitor responses to the audit filters (blanks 66 through 68) must be corrected again to account for this zero offset as follows:

$$Op_{adj} = [1 - (1 - \frac{Op_{ftr}}{100})(1 - \frac{Op_{zero}}{100})]$$

where: Op_{adj} = Correct monitor response

Op_{ftr} = filter opacity, corrected to stack exit conditions
Op_{zero} = audit device zero offset (monitor opacity response to audit device without filter)

Biases in the monitor responses are due to misadjustment of the zero and span functions or to calibration of the monitor with neutral density filters that had not been corrected by the monitor's optical pathlength correlation factor. If the zero and span are not within the proper range, the calibration check data will often be biased in the same direction as the zero and span errors. Even if the zero and span errors are within the proper ranges, the monitor may still not be electronically aligned (i.e., the monitor should be adjusted to indicate 0% opacity during clear stack conditions). If the monitor is calibrated using neutral density filters (usually off-stack) without applying the optical pathlength correction factor to the filters, the monitor responses will agree with the audit filters before they have been corrected to stack exit conditions. If this is the case, the monitor should be recalibrated according to the annual recalibration procedure.

APPENDIX A.

GENERAL TRANSMISSOMETER AUDIT QUESTIONNAIRE

GENERAL TRANSMISSOMETER AUDIT QUESTIONNAIRE

Date ______________ Auditor ________________

PART I.

Plant Information Survey

1. Source Name: ____
2. Location: St. # ____

   City _______________ State _________ Zip __________
3. Mailing Address: ____
4. Plant Contact: ____________________ Title ______________
5. Telephone No.: (   ) ____
6. Plant Category: ____
7. Number of Transmissometers:

	Unit #	MW Output	Control Device(s)	Type of Fuel
a.				
b.				
c.				
d.				
e.				
f.				
g.				
h.				
i.				
j.				

8. Transmissometer Information:

	Manufacturer	Model No.	Serial No.	Date Installed	Date Certified *
a.					
b.					
c.					
d.					
e.					
f.					
g.					
h.					
i.					
j.					

*** If greater than 6 months between installation and certification, determine if any monitor system problems delayed certification testing.**

9. Transmissometer Monitoring Location:

	Monitor Height	Type of Access	Control Unit Location	Monitor Enclosure
a.				
b.				
c.				
d.				
e.				
f.				
g.				
h.				
i.				
j.				

3. Describe the monitor location with respect to stability and freedom from vibration and expansion problems.

____

____

____

____

____

____

4. Data Recording Information:

   a. Data recording equipment ______________________________

      ____

   b. Are data recorded instantaneous ___ or 6 min. avg. ____?

   c. Corrected to stack exit ____yes ____no

5. Have simultaneous Method 9 observations and opacity data been compared, and was there any correlation? ___yes ___no

____

____

6. Frequency of zero and span checks __________hours

GENERAL TRANSMISSOMETER AUDIT QUESTIONNAIRE

Date ____________________ Auditor ____________________

Source Name ______________________ Unit No. ____________

Source ID No. _____________ Monitor Type ____________

PART II.

On Site Survey

Note: Bring Copies of Part II equal to number of transmissometers.

Transceiver Serial No. ___________ Retroreflector Serial No.______

1. Describe the general location of the transmissometer.

   a. Placed upstream ______; or downstream_____ from particulate control equipment.

   b. Distance from nearest bend or flow disturbance:
      (1) Downstream ___________; (2) Upstream _______

   c. Flow disturbances or air leaks observed ____yes _____no.

   d. If yes, describe ____

      ____

   e. Monitor location:
      (1) Stack/duct inside diameter at monitor ____________
      (2) No. of stack/duct diameters upstream from last flow disturbance __________
      (3) No. of stack/duct diameters downstream from last flow disturbance __________

2. Describe the accessibility of the monitoring components for servicing (e.g., height of climb to monitor platform; does monitor platform have adequate space for servicing monitor; is the monitor protected from adverse weather, etc.)

   ____

   ____

   ____

   ____

   ____

7. Monitor Calibration Procedures:

a. Frequency of source personnel checking monitor calibration ____________

b. Criteria used to determine when recalibration is necessary ______________________________________

c. Date of last calibration _______________________

d. Frequency of monitor calibration _______________

e. Description of calibration procedures (e.g., using calibration jig and filters, clear stack zero and span check, off-stack zero and span adjustment, etc.)

____

____

____

f. Is annual clear stack, or clear path zero check performed? ________yes _________no

8. Data and Maintenance Log Review

a. Status of zero checks (latest 30 day period)
Dates covering 30 day period ______________

(1) Internal zero value _________% Op
(2) Highest zero value recorded ________% Op; Date _____
(3) Lowest zero value recorded _________% Op; Date _____
(4) Was zero adjustment performed?_______; Date _________

b. Status of span checks (latest 30 day period);

(1) Internal span value _________% Op
(2) Highest span value recorded ________% Op; Date _____
(3) Lowest span value recorded _________% Op; Date _____
(4) Was span adjustment performed?______; Date _________

c. Downtime (i.e., any period data was not recorded during latest 30 day period). State date and length of downtime.

____

____

8. (continued)

d. Repairs and adjustments (i.e., any preventive or unscheduled maintenance performed during latest 30 day period). Check strip charts for indications of adjustments that are not recorded in logbook. State date and type of maintenance.

____

____

____

____

e. Maintenance intervals. Differentiate between time periods for checking a component and performing maintenance. Also state date of latest check and maintenance action.

(1) Air purge system (changing filters):
    (a) Check. Date __________; Interval __________
    (b) Change. Date __________; Interval __________

(2) Optical surfaces (cleaning):
    (a) Check. Date __________; Interval __________
    (b) Clean. Date __________; Interval __________

(3) Adjust zero and span
    (a) Check. Date __________; Interval __________
    (b) Adjust. Date __________; Interval __________

APPENDIX B.

LEAR SIEGLER RM-41
PERFORMANCE AUDIT DATA SHEETS

LEAR SIEGLER, INC. RM41 PERFORMANCE AUDIT DATA SHEETS

Date ____________ Auditor ______________ Source ID No. _____

AUDIT DATA RETRIEVAL

A. Stack Exit Correlation

1. Stack exit diameter (ft), L_x __________
2. Transmissometer pathlength (ft), L_t __________
3. Calculated OPLR __________
4. Preset OPLR __________

B. Fault Indicator Lamps

	ON	OFF
5. FILTER lamp		
6. SHUTTER lamp		
7. REF lamp		
8. WINDOW lamp		
9. OVER RANGE lamp		

C. Reference Signal Check

10. Original position of measurement knob __________
11. Reference signal current (mA) __________

D. Opacity Measurement Range

12. Original position of opacity range switch __________

E. Instrument Zero Check

13. Chart recorder opacity (% Op) __________

F. Zero Compensation Check

14. Control panel meter optical density (OD) __________

G. Internal Span Check

15. Original position of optical density range switch ________

16. Control panel meter opacity (% Op) ________

17. Chart recorder opacity (% Op) ________

18. Control panel meter input current (mA) ________

19. Control panel meter optical density (OD) ________

H. Span Filter Check

20. Span filter optical density (OD) ________

21. Span filter output current (mA) ________

I. AGC Check

	ON	OFF
22. Lamp status		

J. Alignment Check

	YES	NO
23. Image status (centered)		

K. Retroreflector Windox Check

24. Time of cleaning ________

L. Transceiver Window Check

25. Time at end of waiting period ________

26. Time of cleaning ________

M. Install Audit Device

27. Time of zero of audit device ________

N. Insert Low Range Filter

28. Time at end of waiting period ________

29. Filter opacity (% Op) ________

30. Filter serial number ________

O. Insert Mid Range Filter

31. Time at end of waiting period __________

32. Filter opacity (% Op) __________

33. Filter serial number __________

P. Insert High Range Filter

34. Time at end of waiting period __________

35. Filter opacity (% Op) __________

36. Filter serial number __________

Q. Monitor Response Repeatability

37-48. Time at end of waiting periods:

Low	Mid	High
__________ 37	__________ 38	__________ 39
__________ 40	__________ 41	__________ 42
__________ 43	__________ 44	__________ 45
__________ 46	__________ 47	__________ 48

R. Recheck Zero Compensation

49. Control panel meter optical density (OD) __________

S. Retrieve Retroflector Window Check Data

50. Initial opacity reading (% Op) __________

51. Final opacity reading (% Op) __________

T. Retrieve Transceiver Window Check Data

52. Initial opacity reading (% Op) __________

53. Final opacity reading (% Op) __________

U. Retrieve Audit Device Installation Data

54. Opacity reading (% Op) ________

V. Retrieve All Calibration Filter Data

55-69. Opacity readings (% Op)

Low	Mid	High
________ 55	________ 56	________ 57
________ 58	________ 59	________ 60
________ 61	________ 62	________ 63
________ 64	________ 65	________ 66
________ 67	________ 68	________ 69

AUDIT ANALYSES

A. Stack Exit Correlation Error

70. Error (%):

$$= \left[\frac{(\text{Blank } 4) - (\text{Blank } 3)}{(\text{Blank } 3)}\right] \times 100$$

$$= \left[\frac{(\qquad) - (\qquad)}{(\qquad)}\right] \times 100 = \qquad \underline{\hspace{3cm}}$$

B. Control Panel Meter Correction Factors

71. Opacity scale factor:

$$= \left[\frac{1-10^{-(\text{Blank } 4)(\text{Blank } 20)}}{(\text{Blank } 16)}\right] \times 100$$

$$= \left[\frac{1-10^{-(\qquad)(\qquad)}}{(\qquad)}\right] \times 100 = \qquad \underline{\hspace{3cm}}$$

72. Input scale factor:

$$= \frac{(\text{Blank } 21)}{(\text{Blank } 18)}$$

$$= \frac{(\qquad)}{(\qquad)} = \qquad \underline{\hspace{3cm}}$$

73. Optical density scale factor:

$$= \frac{(\text{Blank } 20)}{[(\text{Blank } 19)/5]}$$

$$= \frac{(\qquad)}{[(\qquad)/5]} = \qquad \underline{\hspace{3cm}}$$

C. Reference Signal Error

74. Error (%):

= [[(Blank 11)/20] -1] x 100

= [[(   )/20] -1] x 100 = __________

D. Zero Compensation Analysis

75. Zero compensation (OD):

= (Blank 14)

= (   ) __________

76. Post cleaning zero compensation (OD):

= (Blank 49)

= (   ) = __________

E. Internal Span Error

77a. Error (% Op):

$= [(\text{Blank } 17)]-[(1-10^{-(\text{Blank } 4)(\text{Blank } 20)})\text{x}100]$

$= [(\qquad)]-[(1-10^{-(\qquad)(\qquad)})\text{x}100] =$ __________

F. Internal Zero Analysis

77b. Zero opacity reading (% Op):

= (Blank 13)

= (   ) = __________

G. Optical Surface Dust Accumulation

78. Transceiver Dust Accumulation (% Op):

= [(Blank 52)]-[(Blank 53)]

= [( )]-[( )] = ________

79. Retroreflector Dust Accumulation (% Op)

= [(Blank 50)]-[(Blank 51)]

= [( )]-[( )] = ________

80. Total Dust Accumulation (% Op):

= [(Blank 78)]+[(Blank 79)]

= [( )]+[( )] = ________

H. OPLR Corrections on Audit Filters

81. Low range filter (% Op):

$= [1-(1-[(\text{Blank } 29)/100])^{2(\text{Blank } 4)}] \times 100$

$= [1-(1-[(\quad)/100])^{2(\quad)}] \times 100 =$ ________

82. Mid rangefilter (% Op):

$= [1-(1-[(\text{Blank } 32)/100])^{2(\text{Blank } 4)}] \times 100$

$= [1-(1-[(\quad)/100])^{2(\quad)}] \times 100 =$ ________

83. High range filter (% Op):

$= [1-(1-[(\text{Blank } 35)/100])^{2(\text{Blank } 4)}] \times 100$

$= [1-(1-[(\quad)/100])^{2(\quad)}] \times 100 =$ ________

I. Determine Mean Error for Low Range Audit Filter

84. Test #1 Difference (% Op):

= (Blank 55)-(Blank 81)

= (   )-(   ) = __________

85. Test #2 Difference (% Op):

= (Blank 58)-(Blank 81)

= (   )-(   ) = __________

86. Test #3 Difference (% Op):

= (Blank 61)-(Blank 81)

= (   )-(   ) = __________

87. Test #4 Difference (% Op):

= (Blank 64)-(Blank 81)

= (   )-(   ) = __________

88. Test #5 Difference (% Op):

= (Blank 67)-(Blank 81)

= (   )-(   ) = __________

89. Mean Error (% Op):

$$= \frac{(\text{Blank } 84)+(\text{Blank } 85)+(\text{Blank } 86)+(\text{Blank } 87)+(\text{Blank } 88)}{5}$$

$$= \frac{(\quad\quad)+(\quad\quad)+(\quad\quad)+(\quad\quad)+(\quad\quad)}{5}$$

= __________

J. Determine Mean Error for Mid Range Audit Filter

90. Test #1 Difference (% Op):

= (Blank 56)-(Blank 82)

= (   )-(   ) = __________

91. Test #2 Difference (% Op):

= (Blank 59)-(Blank 82)

= (   )-(   ) = __________

92. Test #3 Difference (% Op):

= (Blank 62)-(Blank 82)

= (   )-(   ) = __________

93. Test #4 Difference (% Op):

= (Blank 65)-(Blank 82)

= (   )-(   ) = __________

94. Test #5 Difference (% Op):

= (Blank 68)-(Blank 82)

= (   )-(   ) = __________

95. Mean Error (% Op):

$$= \frac{(\text{Blank 90})+(\text{Blank 91})+(\text{Blank 92})+(\text{Blank 93})+(\text{Blank 94})}{5}$$

$$= \frac{(\qquad)+(\qquad)+(\qquad)+(\qquad)+(\qquad)}{5}$$

= __________

K. Determine Mean Error for High Range Audit Filter

96. Test #1 Difference (% Op):

= (Blank 57)-(Blank 83)

= (   )-(   ) = ________

97. Test #2 Difference (% Op):

= (Blank 60)-(Blank 83)

= (   )-(   ) = ________

98. Test #3 Difference (% Op):

= (Blank 63)-(Blank 83)

= (   )-(   ) = ________

99. Test #4 Difference (% Op):

= (Blank 66)-(Blank 83)

= (   )-(   ) = ________

100. Test #5 Difference (% Op):

= (Blank 69)-(Blank 83)

= (   )-(   ) = ________

101. Mean Error (% Op):

$$= \frac{(\text{Blank } 96)+(\text{Blank } 97)+(\text{Blank } 98)+(\text{Blank } 99)+(\text{Blank } 100)}{5}$$

$$= \frac{(\qquad)+(\qquad)+(\qquad)+(\qquad)+(\qquad)}{5}$$

= ________

L. Low Range Audit Filter Confidence Interval

102. $\Sigma\left|\text{Differences}\right|$:

$= |(\text{Blank } 84)|+|(\text{Blank } 85)|+|(\text{Blank } 86)|+|(\text{Blank } 87)|+|(\text{Blank } 88)|$

$= |(\qquad)|+|(\qquad)|+|(\qquad)|+|(\qquad)|+|(\qquad)|$

$= \underline{\qquad\qquad}$

103. $\Sigma(\text{Differences})^2$:

$= (\text{Blank } 84)^2+(\text{Blank } 85)^2+(\text{Blank } 86)^2+(\text{Blank } 87)^2+(\text{Blank } 88)^2$

$= (\qquad)^2+(\qquad)^2+(\qquad)^2+(\qquad)^2+(\qquad)^2$

$= \underline{\qquad\qquad}$

104. Confidence Interval (% Op):

$= 0.2776 \times ([5\text{x}(\text{Blank } 103)]-[(\text{Blank } 102)^2])^{0.5}$

$= 0.2776 \times ([5\text{x}(\qquad)]-[(\qquad)^2])^{0.5} = \underline{\qquad\qquad}$

M. Mid range Audit Filter Confidence Interval

105. $\Sigma\left|\text{Differences}\right|$:

$= |(\text{Blank } 90)|+|(\text{Blank } 91)|+|(\text{Blank } 92)|+|(\text{Blank } 93)|+|(\text{Blank } 94)|$

$= |(\qquad)|+|(\qquad)|+|(\qquad)|+|(\qquad)|+|(\qquad)|$

$= \underline{\qquad\qquad}$

106. $\Sigma(\text{Differences})^2$:

$= (\text{Blank } 90)^2+(\text{Blank } 91)^2+(\text{Blank } 92)^2+(\text{Blank } 93)^2+(\text{Blank } 94)^2$

$= (\qquad)^2+(\qquad)^2+(\qquad)^2+(\qquad)^2+(\qquad)^2$

$= \underline{\qquad\qquad}$

107. Confidence Interval(% Op):

$= 0.2776 \times ([5\text{x}(\text{Blank } 106)]-[(\text{Blank } 105)^2])^{0.5}$

$= 0.2776 \times ([5\text{x}(\qquad)]-[(\qquad)^2])^{0.5} = \underline{\qquad\qquad}$

N. High Range Audit Filter Confidence Interval

108. $\Sigma\,|\text{Differences}|$:

$= |(\text{Blank } 96)| + |(\text{Blank } 97)| + |(\text{Blank } 98)| + |(\text{Blank } 99)| + |(\text{Blank } 100)|$

$= |(\qquad)| + |(\qquad)| + |(\qquad)| + |(\qquad)| + |(\qquad)|$

$=$ __________

109. $\Sigma\,(\text{Differences})^2$:

$= (\text{Blank } 96)^2 + (\text{Blank } 97)^2 + (\text{Blank } 98)^2 + (\text{Blank } 99)^2 + (\text{Blank } 100)^2$

$= (\qquad)^2 + (\qquad)^2 + (\qquad)^2 + (\qquad)^2 + (\qquad)^2$

$=$ __________

110. Confidence Interval(% Op):

$= 0.2776 \times ([5\times(\text{Blank } 109)] - [(\text{Blank } 108)^2])^{0.5}$

$= 0.2776 \times ([5\times(\qquad)] - [(\qquad)^2])^{0.5} =$ __________

O. Calibration Error

111. Low range error (% Op):

$= |(\text{Blank } 89)| + (\text{Blank } 104)$

$= |(\qquad)| + (\qquad) =$ __________

112. Mid range error (% Op):

$= |(\text{Blank } 95)| + (\text{Blank } 107)$

$= |(\qquad)| + (\qquad) =$ __________

113. High range error (% Op):

$= |(\text{Blank } 101)| + (\text{Blank } 110)$

$= |(\qquad)| + (\qquad) =$ __________

APPENDIX C.

DYNATRON 1100
PERFORMANCE AUDIT DATA SHEETS

DYNATRON, INC. 1100 PERFORMANCE AUDIT DATA SHEETS

Date __________ Auditor __________ Source ID NO. ______

AUDIT DATA RETRIEVAL

A. Stack Exit Correlation

1. Stack exit diameter (ft), L_x __________
2. Transmissometer pathlength (ft), L_t __________
3. Calculated pathlength ratio __________
4. Preset pathlength ratio __________

B. Fault Indicator Lamps

	ON	OFF
5. LAMP		
6. WINDOW		
7. AIR PURGE		

C. Internal Zero and Span Check

8. Automatic calibration timer position __________
9. Meter display position __________
10. Zero reading on panel meter (% Op) __________
11. Span reading on panel meter (% Op) __________
12. Zero reading on chart recorder (% Op) __________
13. Span reading on chart recorder (% Op) __________

D. Zero and Span Responses from Operation Manual

14. Zero response (% Op) __________
15. Span response (% Op) __________

E. Alignment Check

	YES	NO
16. Image status (centered)		

F. Transceiver Window Check

17. Time of cleaning __________

G. Retroflector Window Check

18. Time of cleaning __________

H. Insert Low Range Filter

19. Time at end of first waiting period __________
20. Time at end of second waiting period __________
21. Filter opacity (% Op) __________
22. Filter serial number __________
23. Time at end of third waiting period __________

I. Insert Mid Range Filter

24. Time at end of first waiting period __________
25. Filter opacity (% Op) __________
26. Filter serial number __________
27. Time at end of second waiting period __________

J. Insert High Range Filter

28. Time at end of waiting period __________
29. Filter opacity (% Op) __________
30. Filter serial number __________

K. Monitor Response Repeatability

31-54. Time at end of waiting periods:

Low			Mid		High
First Period	Second Period	Third Period	First Period	Second Period	First Period
31	32	33	34	35	36
37	38	39	40	41	42
43	44	45	46	47	48
49	50	51	52	53	54

55. Final waiting period ________

L. Retrieve Transceiver Window Check Data

56. Initial opacity reading (% Op) ________

57. Final opacity reading (% Op) ________

M. Retrieve Retroreflector Window Check Data

58. Initial opacity reading (% Op) ________

59. Final opacity reading (% Op) ________

N. Retrieve All Calibration Filter Data

60-89. Opacity readings (% Op)

Low			Mid		High
First Period	Second Period	Third Period	First Period	Second Period	First Period
60	61	62	63	64	65
66	67	68	69	70	71
72	73	74	75	76	77
78	79	80	81	82	83
84	85	86	87	88	89

90. Final opacity reading (% Op) ____________

AUDIT ANALYSES

A. Stack Exit Correlation Error

91. Error (%):

$$= \left[\frac{(\text{Blank 4}) - (\text{Blank 3})}{(\text{Blank 3})}\right] \times 100$$

$$= \left[\frac{(\qquad) - (\qquad)}{(\qquad)}\right] \times 100 = \underline{\qquad\qquad}$$

B. Control Panel Meter Correction Factor

92. Panel meter factor:

$$= \frac{(\text{Blank 15})}{(\text{Blank 11})}$$

$$= \frac{(\qquad)}{(\qquad)} = \underline{\qquad\qquad}$$

C. Internal Zero and Span Analysis

93. Zero error (% Op):

= (Blank 12)-(Blank 14)

= (   )-(   ) = ____________

94. Span error (% Op):

= (Blank 13)-(Blank 15)

= (   )-(   ) = ____________

D. Optical Surface Dust Accumulation

95a. Transceiver Dust Accumulation (% Op):

= (Blank 56)-(Blank 57)

= ( )-( ) = ________

95b. Retroreflector Dust Accumulation (% Op):

= (Blank 58)-(Blank 59)

= ( )-( ) = ________

95c. Total Dust Accumulation (% Op):

= (Blank 95a)+(Blank 95b)

= ( )+( ) = ________

E. Pathlength Ratio Correction of Audit Slides

96. Low range slide :

$= [1-(\text{Blank } 21/100)]^{2(\text{Blank } 4)}$

$= [1-(\quad /100)]^{2(\quad)}$ = ________

97. Mid range slide :

$= [1-(\text{Blank } 25/100)]^{2(\text{Blank } 4)}$

$= [1-(\quad /100)]^{2(\quad)}$ = ________

98. High range slide :

$= [1-(\text{Blank } 29/100)]^{2(\text{Blank } 4)}$

$= [1-(\quad /100)]^{2(\quad)}$ = ________

F. Calculation of Expected Response to Low Range Audit Slide

99. Test 1 expected response (% Op)

$$= \left[1- \left[1- \frac{(\text{Blank } 60)+(\text{Blank } 62)}{200}\right]\left[(\text{Blank } 96)\right]\right] \times 100$$

$$= \left[1- \left[1- \frac{(\qquad)+(\qquad)}{200}\right]\left[(\qquad)\right]\right] \times 100 = \underline{\qquad\qquad}$$

100. Test 2 expected response (% Op)

$$= \left[1- \left[1- \frac{(\text{Blank } 66)+(\text{Blank } 68)}{200}\right]\left[(\text{Blank } 96)\right]\right] \times 100$$

$$= \left[1- \left[1- \frac{(\qquad)+(\qquad)}{200}\right]\left[(\qquad)\right]\right] \times 100 = \underline{\qquad\qquad}$$

101. Test 3 expected response (% Op)

$$= \left[1- \left[1- \frac{(\text{Blank } 72)+(\text{Blank } 74)}{200}\right]\left[(\text{Blank } 96)\right]\right] \times 100$$

$$= \left[1- \left[1- \frac{(\qquad)+(\qquad)}{200}\right]\left[(\qquad)\right]\right] \times 100 = \underline{\qquad\qquad}$$

102. Test 4 expected response (% Op)

$$= \left[1- \left[1- \frac{(\text{Blank } 78)+(\text{Blank } 80)}{200}\right]\left[(\text{Blank } 96)\right]\right] \times 100$$

$$= \left[1- \left[1- \frac{(\qquad)+(\qquad)}{200}\right]\left[(\qquad)\right]\right] \times 100 = \underline{\qquad\qquad}$$

103. Test 5 expected response (% Op)

$$= \left[1- \left[1- \frac{(\text{Blank } 84)+(\text{Blank } 86)}{200}\right]\left[(\text{Blank } 96)\right]\right] \times 100$$

$$= \left[1- \left[1- \frac{(\qquad)+(\qquad)}{200}\right]\left[(\qquad)\right]\right] \times 100 = \underline{\qquad\qquad}$$

G. Determine Mean Error for Low Range Audit Slide

104. Test 1 difference (% Op)

= (Blank 61)-(Blank 99)

= (   )-(   ) = ________

105. Test 2 difference (% Op)

= (Blank 67)-(Blank 100)

= (   )-(   ) = ________

106. Test 3 difference (% Op)

= (Blank 73)-(Blank 101)

= (   )-(   ) = ________

107. Test 4 difference (% Op)

= (Blank 79)-(Blank 102)

= (   )-(   ) = ________

108. Test 5 difference(% Op)

= (Blank 85)-(Blank 103)

= (   )-(   ) = ________

109. Mean error (% Op)

$$= \frac{(\text{Blank } 104)+(\text{Blank } 105)+(\text{Blank } 106)+(\text{Blank } 107)+(\text{Blank } 108)}{5}$$

$$= \frac{(\qquad)+(\qquad)+(\qquad)+(\qquad)+(\qquad)}{5}$$

= ________

H. Calculation of Expected Response to Mid Range Audit Slide

110. Test 1 expected response (% Op)

$$= \left[1- \left[1- \frac{(\text{Blank } 64)+(\text{Blank } 62)}{200}\right]\left[(\text{Blank } 97)\right]\right] \times 100$$

$$= \left[1- \left[1- \frac{(\qquad)+(\qquad)}{200}\right]\left[(\qquad)\right]\right] \times 100 = \underline{\qquad\qquad}$$

111. Test 2 expected response (% Op)

$$= \left[1- \left[1- \frac{(\text{Blank } 70)+(\text{Blank } 68)}{200}\right]\left[(\text{Blank } 97)\right]\right] \times 100$$

$$= \left[1- \left[1- \frac{(\qquad)+(\qquad)}{200}\right]\left[(\qquad)\right]\right] \times 100 = \underline{\qquad\qquad}$$

112. Test 3 expected response (% Op)

$$= \left[1- \left[1- \frac{(\text{Blank } 76)+(\text{Blank } 74)}{200}\right]\left[(\text{Blank } 97)\right]\right] \times 100$$

$$= \left[1- \left[1- \frac{(\qquad)+(\qquad)}{200}\right]\left[(\qquad)\right]\right] \times 100 = \underline{\qquad\qquad}$$

113. Test 4 expected response (% Op)

$$= \left[1- \left[1- \frac{(\text{Blank } 82)+(\text{Blank } 80)}{200}\right]\left[(\text{Blank } 97)\right]\right] \times 100$$

$$= \left[1- \left[1- \frac{(\qquad)+(\qquad)}{200}\right]\left[(\qquad)\right]\right] \times 100 = \underline{\qquad\qquad}$$

114. Test 5 expected response (% Op)

$$= \left[1- \left[1- \frac{(\text{Blank } 88)+(\text{Blank } 86)}{200}\right]\left[(\text{Blank } 97)\right]\right] \times 100$$

$$= \left[1- \left[1- \frac{(\qquad)+(\qquad)}{200}\right]\left[(\qquad)\right]\right] \times 100 = \underline{\qquad\qquad}$$

I. Determine Mean Error for Mid Range Audit Slide

115. Test 1 difference (% Op)

= (Blank 63)-(Blank 110)

= ( )-( ) = ____________

116. Test 2 difference (% Op)

= (Blank 69)-(Blank 111)

= ( )-( ) = ____________

117. Test 3 difference (% Op)

= (Blank 75)-(Blank 112)

= ( )-( ) = ____________

118. Test 4 difference (% Op)

= (Blank 81)-(Blank 113)

= ( )-( ) = ____________

119. Test 5 difference (% Op)

= (Blank 87)-(Blank 114)

= ( )-( ) = ____________

120. Mean error (% Op)

$$= \frac{(\text{Blank } 115)+(\text{Blank } 116)+(\text{Blank } 117)+(\text{Blank } 118)+(\text{Blank } 119)}{5}$$

$$= \frac{(\quad)+(\quad)+(\quad)+(\quad)+(\quad)}{5}$$

= ____________

J. Calculation of Expected Response to High Range Audit Slide

121. Test 1 expected response (% Op)

$$= \left[1-\left[1-\frac{(\text{Blank }64)+(\text{Blank }66)}{200}\right]\left[(\text{Blank }98)\right]\right] \times 100$$

$$= \left[1-\left[1-\frac{(\qquad)+(\qquad)}{200}\right]\left[(\qquad)\right]\right] \times 100 = \underline{\qquad\qquad}$$

122. Test 2 expected response (% Op)

$$= \left[1-\left[1-\frac{(\text{Blank }70)+(\text{Blank }72)}{200}\right]\left[(\text{Blank }98)\right]\right] \times 100$$

$$= \left[1-\left[1-\frac{(\qquad)+(\qquad)}{200}\right]\left[(\qquad)\right]\right] \times 100 = \underline{\qquad\qquad}$$

123. Test 3 expected response (% Op)

$$= \left[1-\left[1-\frac{(\text{Blank }76)+(\text{Blank }78)}{200}\right]\left[(\text{Blank }98)\right]\right] \times 100$$

$$= \left[1-\left[1-\frac{(\qquad)+(\qquad)}{200}\right]\left[(\qquad)\right]\right] \times 100 = \underline{\qquad\qquad}$$

124. Test 4 expected response (% Op)

$$= \left[1-\left[1-\frac{(\text{Blank }82)+(\text{Blank }84)}{200}\right]\left[(\text{Blank }98)\right]\right] \times 100$$

$$= \left[1-\left[1-\frac{(\qquad)+(\qquad)}{200}\right]\left[(\qquad)\right]\right] \times 100 = \underline{\qquad\qquad}$$

125. Test 5 expected response (% Op)

$$= \left[1-\left[1-\frac{(\text{Blank }88)+(\text{Blank }90)}{200}\right]\left[(\text{Blank }98)\right]\right] \times 100$$

$$= \left[1-\left[1-\frac{(\qquad)+(\qquad)}{200}\right]\left[(\qquad)\right]\right] \times 100 = \underline{\qquad\qquad}$$

K. Determine Mean Error for High Range Audit Slide

126. Test 1 difference (% Op)

= (Blank 65)-(Blank 121)

= (   )-(   ) = __________

127. Test 2 difference (% Op)

= (Blank 71)-(Blank 122)

= (   )-(   ) = __________

128. Test 3 difference (% Op)

= (Blank 77)-(Blank 123)

= (   )-(   ) = __________

129. Test 4 difference (% Op)

= (Blank 83)-(Blank 124)

= (   )-(   ) = __________

130. Test 5 difference (% Op)

= (Blank 89)-(Blank 125)

= (   )-(   ) = __________

131. Mean error (% Op)

$$= \frac{(\text{Blank } 126)+(\text{Blank } 127)+(\text{Blank } 128)+(\text{Blank } 129)+(\text{Blank } 130)}{5}$$

$$= \frac{(\quad\quad)+(\quad\quad)+(\quad\quad)+(\quad\quad)+(\quad\quad)}{5}$$

= __________

L. Low Range Audit Slide Confidence Interval

132. $\Sigma\left|\text{Differences}\right|$:

$= \left|(\text{Blank } 104)\right| + \left|(\text{Blank } 105)\right| + \left|(\text{Blank } 106)\right| + \left|(\text{Blank } 107)\right| + \left|(\text{Blank } 108)\right|$

$= \left|(\qquad\qquad)\right| + \left|(\qquad\qquad)\right| + \left|(\qquad\qquad)\right| + \left|(\qquad\qquad)\right| + \left|(\qquad\qquad)\right|$

= __________

133. $\Sigma(\text{Differences})^2$:

$= (\text{Blank } 104)^2 + (\text{Blank } 105)^2 + (\text{Blank } 106)^2 + (\text{Blank } 107)^2 + (\text{Blank } 108)^2$

$= (\qquad\qquad)^2 + (\qquad\qquad)^2 + (\qquad\qquad)^2 + (\qquad\qquad)^2 + (\qquad\qquad)^2$

= __________

134. Confidence Interval(% Op)

$= 0.2776 \times ([5 \times (\text{Blank } 133)] - [(\text{Blank } 132)^2])^{0.5}$

$= 0.2776 \times ([5 \times (\qquad\qquad)] - [(\qquad\qquad)^2])^{0.5} =$ __________

M. Mid Range Audit Slide Confidence Interval

135. $\Sigma\left|\text{Differences}\right|$:

$= \left|(\text{Blank } 115)\right| + \left|(\text{Blank } 116)\right| + \left|(\text{Blank } 117)\right| + \left|(\text{Blank } 118)\right| + \left|(\text{Blank } 119)\right|$

$= \left|(\qquad\qquad)\right| + \left|(\qquad\qquad)\right| + \left|(\qquad\qquad)\right| + \left|(\qquad\qquad)\right| + \left|(\qquad\qquad)\right|$

= __________

136. $\Sigma(\text{Differences})^2$:

$= (\text{Blank } 115)^2 + (\text{Blank } 116)^2 + (\text{Blank } 117)^2 + (\text{Blank } 118)^2 + (\text{Blank } 119)^2$

$= (\qquad\qquad)^2 + (\qquad\qquad)^2 + (\qquad\qquad)^2 + (\qquad\qquad)^2 + (\qquad\qquad)^2$

= __________

137. Confidence Interval(% Op)

$= 0.2776 \times ([5 \times (\text{Blank } 136)] - [(\text{Blank } 135)^2])^{0.5}$

$= 0.2776 \times ([5 \times (\qquad\qquad)] - [(\qquad\qquad)^2])^{0.5} =$ __________

N. High Range Audit Slide Confidence Interval

138. $\Sigma\left|\text{Differences}\right|$:

$= |(\text{Blank }126)|+|(\text{Blank }127)|+|(\text{Blank }128)|+|(\text{Blank }129)|+|(\text{Blank }130)|$

$= |(\qquad\qquad)|+|(\qquad\qquad)|+|(\qquad\qquad)|+|(\qquad\qquad)|+|(\qquad\qquad)|$

= __________

139. $\Sigma(\text{Differences})^2$:

$= (\text{Blank }126)^2+(\text{Blank }127)^2+(\text{Blank }128)^2+(\text{Blank }129)^2+(\text{Blank }130)^2$

$= (\qquad\qquad)^2+(\qquad\qquad)^2+(\qquad\qquad)^2+(\qquad\qquad)^2+(\qquad\qquad)^2$

= __________

140. Confidence Interval (% Op)

$= 0.2776 \times ([5\times(\text{Blank }139)]-[(\text{Blank }138)^2])^{0.5}$

$= 0.2776 \times ([5\times(\qquad\qquad)]-[(\qquad\qquad)^2])^{0.5} =$ __________

O. Calibration Error

141. Low range error (% Op)

$= |(\text{Blank }109)|+(\text{Blank }134)$

$= |(\qquad\qquad)|+(\qquad\qquad) =$ __________

142. Midrange error (% Op)

$= |(\text{Blank }120)|+(\text{Blank }137)$

$= |(\qquad\qquad)|+(\qquad\qquad) =$ __________

143. High range error (% Op)

$= |(\text{Blank }131)|+(\text{Blank }140)$

$= |(\qquad\qquad)|+(\qquad\qquad) =$ __________

APPENDIX D.

CONTRAVES 400
PERFORMANCE AUDIT DATA SHEETS

CONTRAVES-GOERZ CORP. 400 PERFORMANCE AUDIT DATA SHEETS

Date ___________ Auditor ________________ Source ID No. _______

AUDIT DATA RETRIEVAL

A. Stack Exit Correlation

1. Stack exit diameter (ft), L_x __________
2. Transmissometer pathlength (ft), L_t __________
3. Calculated STR __________
4. Preset STR __________

B. Fault Indicator Lamps

	ON	OFF
5. CAL FAULT		
6. DIRTY WINDOW		
7. PURGE AIR		
8. STACK POWER		
9. LAMP FAILURE		
10. ALARM		

C. Instrument Zero Check (Control Unit)

11. Chart recorder opacity (% Op) __________

D. Internal Span Check (Control Unit)

12. Control panel meter opacity (% Op) __________
13. Chart recorder opacity (% Op) __________

E. Span Value Check

14. Chopper span opacity (% Op) __________

F. Zero Check at Transceiver (no Control Unit)

15. Time of check __________

16. Transceiver meter opacity (% Op) __________

G. Span Check at Transceiver (no Control Unit)

17. Time of check __________

18. Transceiver meter opacity (% Op) __________

H. Alignment Check

	YES	NO
19. Image status (centered)		

I. Retroreflector Window Check

20. Time of cleaning __________

J. Transceiver Window Check

21. Time of cleaning __________

K. Install Audit Device

22. Time at end of waiting period __________

L. Insert Low Range Filter

23. Time at end of waiting period __________

24. Filter opacity (% Op) __________

25. Filter serial number __________

M. Insert Mid Range Filter

26. Time at end of waiting period ____________

27. Filter opacity (% Op) ____________

28. Filter serial number ____________

N. Insert High Range Filter

29. Time at end of waiting period ____________

30. Filter opacity (% Op) ____________

31. Filter serial number ____________

O. Monitor Response Repeatability

32-43. Time at end of waiting periods:

Low	Mid	High
32	33	34
35	36	37
38	39	40
41	42	43

P. Retrieve Internal Zero Response (no Control Unit)

44. Chart recorder opacity (% Op) ____________

Q. Retrieve Internal Span Response (no Control Unit)

45. Chart recorder opacity (% Op) ____________

R. Retrieve Retroreflector Window Check Data

46. Initial opacity reading (% Op) ____________

47. Final opacity reading (% Op) ____________

S. Retrieve Transceiver Window Check Data

48. Initial opacity reading (% Op) __________

49. Final opacity reading (% Op) __________

T. Retrieve Audit Device Installation Data

50. Opacity reading (% Op) __________

U. Retrieve All Calibration Filter Data

51-65. Opacity readings (% Op)

Low	Mid	High
__________ 51	__________ 52	__________ 53
__________ 54	__________ 55	__________ 56
__________ 57	__________ 58	__________ 59
__________ 60	__________ 61	__________ 62
__________ 63	__________ 64	__________ 65

AUDIT ANALYSES

A. Stack Exit Correlation Error

66. Error (%):

$$= \left[\frac{(\text{Blank } 4) - (\text{Blank } 3)}{(\text{Blank } 3)}\right] \times 100$$

$$= \left[\frac{(\qquad) - (\qquad)}{(\qquad)}\right] \times 100 = \underline{\qquad\qquad}$$

B. Meter Correction Factor

67. Panel meter factor:

$$= \frac{(\text{Blank } 14)}{(\text{Blank } 12)}$$

$$= \frac{(\qquad)}{(\qquad)} = \underline{\qquad\qquad}$$

68. Transceiver meter factor:

$$= \frac{(\text{Blank } 14)}{(\text{Blank } 18)}$$

$$= \frac{(\qquad)}{(\qquad)} = \underline{\qquad\qquad}$$

C. Internal Span Error

69. Span error with control unit (% Op)

$$= (\text{Blank } 13) - (\text{Blank } 14)$$

$$= (\qquad) - (\qquad) = \underline{\qquad\qquad}$$

70. Span error without control unit (% Op)

= (Blank 45) - (Blank 14)

= (   ) - (   ) = ________

D. Optical Surface Dust Accumulation

71a. Transceiver Dust Accumulation (% Op):

= (Blank 48) - (Blank 49)

= (   ) - (   ) = ________

71b. Retroreflector Dust Accumulation (% Op):

= (Blank 46) - (Blank 47)

= (   ) - (   ) = ________

71c. Total Dust Accumulation (% Op):

= (Blank 71a) + (Blank 71b)

= (   ) - (   ) = ________

E. Pathlength Ratio Corrections on Audit Filters

72. Low range filter (% Op):

$= [1-(1-[(\text{Blank 24})/100])^{(\text{Blank 4})}] \times 100$

$= [1-(1-[(\qquad)/100])^{(\qquad)}] \times 100 =$ ________

73. Mid range filter (% Op):

$= [1-(1-[(\text{Blank 27})/100])^{(\text{Blank 4})}] \times 100$

$= [1-(1-[(\qquad)/100])^{(\qquad)}] \times 100 =$ ________

74. High range filter (% Op):

$= [1-(1-[(\text{Blank 30})/100])^{(\text{Blank 4})}] \times 100$

$= [1-(1-[(\qquad)/100])^{(\qquad)}] \times 100 =$ ________

F. Determine Mean Error for Low Range Audit Filter

75. Test #1 difference (% Op)

= (Blank 51)-(Blank 72)

= (   )-(   ) = ________

76. Test #2 difference (% Op)

= (Blank 54)-(Blank 72)

= (   )-(   ) = ________

77. Test #3 difference (% Op)

= (Blank 57)-(Blank 72)

= (   )-(   ) = ________

78. Test #4 difference (% Op)

= (Blank 60)-(Blank 72)

= (   )-(   ) = ________

79. Test #5 difference (% Op)

= (Blank 63)-(Blank 72)

= (   )-(   ) = ________

80. Mean error (% Op)

$$= \frac{(\text{Blank } 75)+(\text{Blank } 76)+(\text{Blank } 77)+(\text{Blank } 78)+(\text{Blank } 79)}{5}$$

$$= \frac{(\qquad)+(\qquad)+(\qquad)+(\qquad)+(\qquad)}{5}$$

= ________

G. Determine Mean Error for Mid Range Audit Filter

81. Test #1 difference (% Op)

= (Blank 52)-(Blank 73)

= ( )-( ) = ________

82. Test #2 difference (% Op)

= (Blank 55)-(Blank 73)

= ( )-( ) = ________

83. Test #3 difference (% Op)

= (Blank 58)-(Blank 73)

= ( )-( ) = ________

84. Test #4 difference (% Op)

= (Blank 61)-(Blank 73)

= ( )-( ) = ________

85. Test #5 difference (% Op)

= (Blank 64)-(Blank 73)

= ( )-( ) = ________

86. Mean error (% Op)

$$= \frac{(\text{Blank } 81)+(\text{Blank } 82)+(\text{Blank } 83)+(\text{Blank } 84)+(\text{Blank } 85)}{5}$$

$$= \frac{(\quad)+(\quad)+(\quad)+(\quad)+(\quad)}{5}$$

= ________

H. Determine Mean Error for High Range Audit Filter

87. Test #1 difference (% Op)

= (Blank 53)-(Blank 74)

= (   )-(   ) = __________

88. Test #2 difference (% Op)

= (Blank 56)-(Blank 74)

= (   )-(   ) = __________

89. Test #3 difference (% Op)

= (Blank 59)-(Blank 74)

= (   )-(   ) = __________

90. Test #4 difference (% Op)

= (Blank 62)-(Blank 74)

= (   )-(   ) = __________

91. Test #5 difference (% Op)

= (Blank 65)-(Blank 74)

= (   )-(   ) = __________

92. Mean error (% Op)

$$= \frac{(\text{Blank 87})+(\text{Blank 88})+(\text{Blank 89})+(\text{Blank 90})+(\text{Blank 91})}{5}$$

$$= \frac{(\qquad)+(\qquad)+(\qquad)+(\qquad)+(\qquad)}{5}$$

= __________

I. Low Range Audit Filter Confidence Interval

93. $\Sigma|\text{Differences}|$:

$= |(\text{Blank } 75)|+|(\text{Blank } 76)|+|(\text{Blank } 77)|+|(\text{Blank } 78)|+|(\text{Blank } 79)|$

$= |(\qquad)|+|(\qquad)|+|(\qquad)|+|(\qquad)|+|(\qquad)|$

= ____________

94. $\Sigma(\text{Differences})^2$:

$= (\text{Blank } 75)^2+(\text{Blank } 76)^2+(\text{Blank } 77)^2+(\text{Blank } 78)^2+(\text{Blank } 79)^2$

$= (\qquad)^2+(\qquad)^2+(\qquad)^2+(\qquad)^2+(\qquad)^2$

= ____________

95. Confidence interval (% Op)

$= 0.2776 \times ([5\times(\text{Blank } 94)]-[(\text{Blank } 93)^2])^{0.5}$

$= 0.2776 \times ([5\times(\qquad)]-[(\qquad)^2])^{0.5} =$ ____________

J. Mid Range Audit Filter Confidence Interval

96. $\Sigma|\text{Differences}|$:

$= |(\text{Blank } 81)|+|(\text{Blank } 82)|+|(\text{Blank } 83)|+|(\text{Blank } 84)|+|(\text{Blank } 85)|$

$= |(\qquad)|+|(\qquad)|+|(\qquad)|+|(\qquad)|+|(\qquad)|$

= ____________

97. $\Sigma(\text{Differences})^2$:

$= (\text{Blank } 81)^2+(\text{Blank } 82)^2+(\text{Blank } 83)^2+(\text{Blank } 84)^2+(\text{Blank } 85)^2$

$= (\qquad)^2+(\qquad)^2+(\qquad)^2+(\qquad)^2+(\qquad)^2$

= ____________

98. Confidence interval (% Op)

$= 0.2776 \times ([5\times(\text{Blank } 97)]-[(\text{Blank } 96)^2])^{0.5}$

$= 0.2776 \times ([5\times(\qquad)]-[(\qquad)^2])^{0.5} =$ ____________

K. High Range Audit Filter Confidence Interval

99. $\Sigma\left|\text{Differences}\right|$:

$= |(\text{Blank } 87)|+|(\text{Blank } 88)|+|(\text{Blank } 89)|+|(\text{Blank } 90)|+|(\text{Blank } 91)|$

$= |(\qquad)|+|(\qquad)|+|(\qquad)|+|(\qquad)|+|(\qquad)|$

= __________

100. $\Sigma(\text{Differences})^2$:

$= (\text{Blank } 87)^2+(\text{Blank } 88)^2+(\text{Blank } 89)^2+(\text{Blank } 90)^2+(\text{Blank } 91)^2$

$= (\qquad)^2+(\qquad)^2+(\qquad)^2+(\qquad)^2+(\qquad)^2$

= __________

101. Confidence interval (% Op)

$= 0.2776 \text{ x } ([5\text{x}(\text{Blank } 100)]-[(\text{Blank } 99)^2])^{0.5}$

$= 0.2776 \text{ x } ([5\text{x}(\qquad)]-[(\qquad)^2])^{0.5} =$ __________

L. Calibration Error

102. Low range error (% Op)

$= |(\text{Blank } 80)|+(\text{Blank } 95)$

$= |(\qquad)|+(\qquad) =$ __________

103. Midrange error (% Op)

$= |(\text{Blank } 86)|+(\text{Blank } 98)$

$= |(\qquad)|+(\qquad) =$ __________

104. High range error (% Op)

$= |(\text{Blank } 92)|+(\text{Blank } 101)$

$= |(\qquad)|+(\qquad) =$ __________

APPENDIX E.

EDC 1000A
PERFORMANCE AUDIT DATA SHEETS

ENVIRONMENTAL DATA CORP. 1000A PERFORMANCE AUDIT DATA SHEETS

Date ______________ Auditor ________________ Source ID No. _______

AUDIT DATA RETRIEVAL

A. Stack Exit Correlation

1. Stack exit diameter (ft), L_x __________
2. Transmissometer pathlength (ft), L_t __________
3. Calculated pathlength ratio __________
4. Preset pathlength ratio __________

B. Internal Zero and Span Check (Control Room)

5. Zero reading on chart recorder (% Op) __________
6. Span reading on chart recorder (% Op) __________

C. Zero and Span Responses from Operation Manual

7. Zero response (% Op) __________
8. Span response (% Op) __________

D. Internal Zero and Span Check (Transceiver)

9. Time of zero check __________
10. Time of span check __________

E. Transceiver Window Check

11. Time of cleaning __________

F. Retroflector Window Check

12. Time of cleaning __________

G. Insert Low Range Filter

13. Time at end of first waiting period ____________
14. Time at end of second waiting period ____________
15. Filter opacity (% Op) ____________
16. Filter serial number ____________
17. Time at end of third waiting period ____________

H. Insert Mid Range Filter

18. Time at end of first waiting period ____________
19. Filter opacity (% Op) ____________
20. Filter serial number ____________
21. Time at end of second waiting period ____________

I. Insert High Range Filter

22. Time at end of waiting period ____________
23. Filter opacity (% Op) ____________
24. Filter serial number ____________

J. Monitor Response Repeatability

25-48. Time at end of waiting periods:

Low			Mid		High
First Period	Second Period	Third Period	First Period	Second Period	First Period
25	26	27	28	29	30
31	32	33	34	35	36
37	38	39	40	41	42
43	44	45	46	47	48

49. Final waiting period ____________

K. Internal Zero and Span Response Retrieval (Transceiver)

50. Zero response (% Op) ____________

51. Span response (% Op) ____________

L. Retrieve Transceiver Window Check Data

52. Initial opacity reading (% Op) ____________

53. Final opacity reading (% Op) ____________

M. Retrieve Retroreflector Window Check Data

54. Initial opacity reading (% Op) ____________

55. Final opacity reading (% Op) ____________

N. Retrieve All Calibration Filter Data

56-85. Opacity readings (% Op)

Low			Mid		High
First Period	Second Period	Third Period	First Period	Second Period	First Period
56	57	58	59	60	61
62	63	64	65	66	67
68	69	70	71	72	73
74	75	76	77	78	79
80	81	82	83	84	85

86. Final opacity reading (% Op)

A. Stack Exit Correlation Error

87. Error (%):

$$= \left[\frac{(\text{Blank 4}) - (\text{Blank 3})}{(\text{Blank 3})}\right] \times 100$$

$$= \left[\frac{(\qquad) - (\qquad)}{(\qquad)}\right] \times 100 = \underline{\qquad\qquad}$$

B. Internal Zero and Span Analysis (Control Room)

88. Zero error (% Op):

= (Blank 5)-(Blank 7)

= (   )-(   ) = ________

89. Span error (% Op):

= (Blank 6)-(Blank 8)

= (   )-(   ) = ________

C. Internal Zero and Span Analysis (Transceiver)

90. Zero error (% Op):

= (Blank 50)-(Blank 7)

= (   )-(   ) = ________

91. Span error (% Op):

= (Blank 51)-(Blank 8)

= (   )-(   ) = ________

D. Optical Surface Dust Accumulation

92a. Transceiver Dust Accumulation (% Op):

= (Blank 52)-(Blank 53)

= (   )-(   ) = __________

92b. Retroreflector Dust Accumulation (% Op):

= (Blank 54)-(Blank 55)

= (   )-(   ) = __________

92c. Total Dust Accumulation (% Op):

= (Blank 92a)-(Blank 92b)

= (   )-(   ) = __________

E. Pathlength Ratio Correction on Audit Slides

93. Low range slide :

$= [1-(\text{Blank } 15/100)]^{2(\text{Blank } 4)}$

$= [1-(\qquad\quad /100)]^{2(\qquad)} =$ __________

94. Mid range slide :

$= [1-(\text{Blank } 19/100)]^{2(\text{Blank } 4)}$

$= [1-(\qquad\quad /100)]^{2(\qquad)} =$ __________

95. High range slide :

$= [1-(\text{Blank } 23/100)]^{2(\text{Blank } 4)}$

$= [1-(\qquad\quad /100)]^{2(\qquad)} =$ __________

F. Calculation of Expected Response to Low Range Audit Slide

96. Test 1 expected response (% Op)

$$= \left[1- \left[1- \frac{(\text{Blank } 56)+(\text{Blank } 58)}{200}\right]\left[(\text{Blank } 93)\right]\right] \times 100$$

$$= \left[1- \left[1- \frac{(\qquad)+(\qquad)}{200}\right]\left[(\qquad)\right]\right] \times 100 = \underline{\qquad\qquad}$$

97. Test 2 expected response (% Op)

$$= \left[1- \left[1- \frac{(\text{Blank } 62)+(\text{Blank } 64)}{200}\right]\left[(\text{Blank } 93)\right]\right] \times 100$$

$$= \left[1- \left[1- \frac{(\qquad)+(\qquad)}{200}\right]\left[(\qquad)\right]\right] \times 100 = \underline{\qquad\qquad}$$

98. Test 3 expected response (% Op)

$$= \left[1- \left[1- \frac{(\text{Blank } 68)+(\text{Blank } 70)}{200}\right]\left[(\text{Blank } 93)\right]\right] \times 100$$

$$= \left[1- \left[1- \frac{(\qquad)+(\qquad)}{200}\right]\left[(\qquad)\right]\right] \times 100 = \underline{\qquad\qquad}$$

99. Test 4 expected response (% Op)

$$= \left[1- \left[1- \frac{(\text{Blank } 74)+(\text{Blank } 76)}{200}\right]\left[(\text{Blank } 93)\right]\right] \times 100$$

$$= \left[1- \left[1- \frac{(\qquad)+(\qquad)}{200}\right]\left[(\qquad)\right]\right] \times 100 = \underline{\qquad\qquad}$$

100. Test 5 expected response (% Op)

$$= \left[1- \left[1- \frac{(\text{Blank } 80)+(\text{Blank } 82)}{200}\right]\left[(\text{Blank } 93)\right]\right] \times 100$$

$$= \left[1- \left[1- \frac{(\qquad)+(\qquad)}{200}\right]\left[(\qquad)\right]\right] \times 100 = \underline{\qquad\qquad}$$

G. Determine Mean Error for Low Range Audit Slide

101. Test 1 difference (% Op)

= (Blank 57)-(Blank 96)

= (   )-(   ) = __________

102. Test 2 difference (% Op)

= (Blank 63)-(Blank 97)

= (   )-(   ) = __________

103. Test 3 difference (% Op)

= (Blank 69)-(Blank 98)

= (   )-(   ) = __________

104. Test 4 difference (% Op)

= (Blank 75)-(Blank 99)

= (   )-(   ) = __________

105. Test 5 difference (% Op)

= (Blank 81)-(Blank 100)

= (   )-(   ) = __________

106. Mean error (% Op)

$$= \frac{(\text{Blank } 101)+(\text{Blank } 102)+(\text{Blank } 103)+(\text{Blank } 104)+(\text{Blank } 105)}{5}$$

$$= \frac{(\qquad)+(\qquad)+(\qquad)+(\qquad)+(\qquad)}{5}$$

= __________

H. Calculation of Expected Response to Mid Range Audit Slide

107. Test 1 expected response (% Op)

$$= \left[1- \left[1- \frac{(\text{Blank } 58)+(\text{Blank } 60)}{200}\right]\left[(\text{Blank } 94)\right]\right] \text{x } 100$$

$$= \left[1- \left[1- \frac{(\qquad)+(\qquad)}{200}\right]\left[(\qquad)\right]\right] \text{x } 100 = \underline{\qquad\qquad}$$

108. Test 2 expected response (% Op)

$$= \left[1- \left[1- \frac{(\text{Blank } 64)+(\text{Blank } 66)}{200}\right]\left[(\text{Blank } 94)\right]\right] \text{x } 100$$

$$= \left[1- \left[1- \frac{(\qquad)+(\qquad)}{200}\right]\left[(\qquad)\right]\right] \text{x } 100 = \underline{\qquad\qquad}$$

109. Test 3 expected response (% Op)

$$= \left[1- \left[1- \frac{(\text{Blank } 70)+(\text{Blank } 72)}{200}\right]\left[(\text{Blank } 94)\right]\right] \text{x } 100$$

$$= \left[1- \left[1- \frac{(\qquad)+(\qquad)}{200}\right]\left[(\qquad)\right]\right] \text{x } 100 = \underline{\qquad\qquad}$$

110. Test 4 expected response (% Op)

$$= \left[1- \left[1- \frac{(\text{Blank } 76)+(\text{Blank } 78)}{200}\right]\left[(\text{Blank } 94)\right]\right] \text{x } 100$$

$$= \left[1- \left[1- \frac{(\qquad)+(\qquad)}{200}\right]\left[(\qquad)\right]\right] \text{x } 100 = \underline{\qquad\qquad}$$

111. Test 5 expected response (% Op)

$$= \left[1- \left[1- \frac{(\text{Blank } 82)+(\text{Blank } 84)}{200}\right]\left[(\text{Blank } 94)\right]\right] \text{x } 100$$

$$= \left[1- \left[1- \frac{(\qquad)+(\qquad)}{200}\right]\left[(\qquad)\right]\right] \text{x } 100 = \underline{\qquad\qquad}$$

I. Determine Mean Error for Mid Range Audit Slide

112. Test 1 difference (% Op)

= (Blank 59)-(Blank 107)

= ( )-( ) = __________

113. Test 2 difference (% Op)

= (Blank 65)-(Blank 108)

= ( )-( ) = __________

114. Test 3 difference (% Op)

= (Blank 71)-(Blank 109)

= ( )-( ) = __________

115. Test 4 difference (% Op)

= (Blank 77)-(Blank 110)

= ( )-( ) = __________

116. Test 5 difference (% Op)

= (Blank 83)-(Blank 111)

= ( )-( ) = __________

117. Mean error (% Op)

$$= \frac{(\text{Blank } 112)+(\text{Blank } 113)+(\text{Blank } 114)+(\text{Blank } 115)+(\text{Blank } 116)}{5}$$

$$= \frac{(\quad)+(\quad)+(\quad)+(\quad)+(\quad)}{5}$$

= __________

J. Calculation of Expected Response to High Range Audit Slide

118. Test 1 expected response (% Op)

$$= \left[1- \left[1- \frac{(\text{Blank } 60)+(\text{Blank } 62)}{200}\right]\left[(\text{Blank } 95)\right]\right] \times 100$$

$$= \left[1- \left[1- \frac{(\qquad\quad)+(\qquad\quad)}{200}\right]\left[(\qquad\quad)\right]\right] \times 100 = \underline{\qquad\qquad}$$

119. Test 2 expected response (% Op)

$$= \left[1- \left[1- \frac{(\text{Blank } 66)+(\text{Blank } 68)}{200}\right]\left[(\text{Blank } 95)\right]\right] \times 100$$

$$= \left[1- \left[1- \frac{(\qquad\quad)+(\qquad\quad)}{200}\right]\left[(\qquad\quad)\right]\right] \times 100 = \underline{\qquad\qquad}$$

120. Test 3 expected response (% Op)

$$= \left[1- \left[1- \frac{(\text{Blank } 72)+(\text{Blank } 74)}{200}\right]\left[(\text{Blank } 95)\right]\right] \times 100$$

$$= \left[1- \left[1- \frac{(\qquad\quad)+(\qquad\quad)}{200}\right]\left[(\qquad\quad)\right]\right] \times 100 = \underline{\qquad\qquad}$$

121. Test 4 expected response (% Op)

$$= \left[1- \left[1- \frac{(\text{Blank } 78)+(\text{Blank } 80)}{200}\right]\left[(\text{Blank } 95)\right]\right] \times 100$$

$$= \left[1- \left[1- \frac{(\qquad\quad)+(\qquad\quad)}{200}\right]\left[(\qquad\quad)\right]\right] \times 100 = \underline{\qquad\qquad}$$

122. Test 5 expected response (% Op)

$$= \left[1- \left[1- \frac{(\text{Blank } 84)+(\text{Blank } 86)}{200}\right]\left[(\text{Blank } 95)\right]\right] \times 100$$

$$= \left[1- \left[1- \frac{(\qquad\quad)+(\qquad\quad)}{200}\right]\left[(\qquad\quad)\right]\right] \times 100 = \underline{\qquad\qquad}$$

K. Determine Mean Error for High Range Audit Slide

123. Test 1 difference (% Op)

= (Blank 61)-(Blank 118)

= ( )-( ) = ______

124. Test 2 difference (% Op)

= (Blank 67)-(Blank 119)

= ( )-( ) = ______

125. Test 3 difference (% Op)

= (Blank 73)-(Blank 120)

= ( )-( ) = ______

126. Test 4 difference (% Op)

= (Blank 79)-(Blank 121)

= ( )-( ) = ______

127. Test 5 difference (% Op)

= (Blank 85)-(Blank 122)

= ( )-( ) = ______

128. Mean error (% Op)

$$= \frac{(\text{Blank } 123)+(\text{Blank } 124)+(\text{Blank } 125)+(\text{Blank } 126)+(\text{Blank } 127)}{5}$$

$$= \frac{(\quad)+(\quad)+(\quad)+(\quad)+(\quad)}{5}$$

= ______

L. Low Range Audit Slide Confidence Interval

129. $\Sigma\ |\text{Differences}|$:

$= |(\text{Blank } 101)| + |(\text{Blank } 102)| + |(\text{Blank } 103)| + |(\text{Blank } 104)| + |(\text{Blank } 105)|$

$= |(\qquad)| + |(\qquad)| + |(\qquad)| + |(\qquad)| + |(\qquad)|$

= __________

130. $\Sigma\,(\text{Differences})^2$:

$= (\text{Blank } 101)^2 + (\text{Blank } 102)^2 + (\text{Blank } 103)^2 + (\text{Blank } 104)^2 + (\text{Blank } 105)^2$

$= (\qquad)^2 + (\qquad)^2 + (\qquad)^2 + (\qquad)^2 + (\qquad)^2$

= __________

131. Confidence Interval (% Op)

$= 0.2776 \times ([5\times(\text{Blank } 130)] - [(\text{Blank } 129)^2])^{0.5}$

$= 0.2776 \times ([5\times(\qquad)] - [(\qquad)^2])^{0.5} =$ __________

M. Mid Range Audit Slide Confidence Interval

132. $\Sigma\ |\text{Differences}|$:

$= |(\text{Blank } 112)| + |(\text{Blank } 113)| + |(\text{Blank } 114)| + |(\text{Blank } 115)| + |(\text{Blank } 116)|$

$= |(\qquad)| + |(\qquad)| + |(\qquad)| + |(\qquad)| + |(\qquad)|$

= __________

133. $\Sigma\,(\text{Differences})^2$:

$= (\text{Blank } 112)^2 + (\text{Blank } 113)^2 + (\text{Blank } 114)^2 + (\text{Blank } 115)^2 + (\text{Blank } 116)^2$

$= (\qquad)^2 + (\qquad)^2 + (\qquad)^2 + (\qquad)^2 + (\qquad)^2$

= __________

134. Confidence Interval (% Op)

$= 0.2776 \times ([5\times(\text{Blank } 133)] - [(\text{Blank } 132)^2])^{0.5}$

$= 0.2776 \times ([5\times(\qquad)] - [(\qquad)^2])^{0.5} =$ __________

N. High Range Audit Slide Confidence Interval

135. $\Sigma\,\left|\text{Differences}\right|$:

$= |(\text{Blank } 123)|+|(\text{Blank } 124)|+|(\text{Blank } 125)|+|(\text{Blank } 126)|+|(\text{Blank } 127)|$

$= |(\qquad)|+|(\qquad)|+|(\qquad)|+|(\qquad)|+|(\qquad)|$

= ________

136. $\Sigma\,(\text{Differences})^2$:

$= (\text{Blank } 123)^2+(\text{Blank } 124)^2+(\text{Blank } 125)^2+(\text{Blank } 126)^2+(\text{Blank } 127)^2$

$= (\qquad)^2+(\qquad)^2+(\qquad)^2+(\qquad)^2+(\qquad)^2$

= ________

137. Confidence Interval (% Op)

$= 0.2776 \times ([5 \times (\text{Blank } 136)]-[(\text{Blank } 135)^2])^{0.5}$

$= 0.2776 \times ([5 \times (\qquad)]-[(\qquad)^2])^{0.5} =$ ________

O. Calibration Error

138. Low range error (% Op)

$= |(\text{Blank } 106)|+(\text{Blank } 131)$

$= |(\qquad)|+(\qquad) =$ ________

139. Mid range error (% Op)

$= |(\text{Blank } 117)|+(\text{Blank } 134)$

$= |(\qquad)|+(\qquad) =$ ________

140. High range error (% Op)

$= |(\text{Blank } 128)|+(\text{Blank } 137)$

$= |(\qquad)|+(\qquad) =$ ________

APPENDIX F.

THERMO ELECTRON D-R280 PERFORMANCE DATA SHEETS

THERMO ELECTRON CORP. D-R280 AV PERFORMANCE AUDIT DATA SHEETS

Date ____________ Auditor ________________________ Source ID No. ________

AUDIT DATA RETRIEVAL

A. Stack Exit Correlation

1. Stack exit diameter (ft), L_x ________
2. Transmissometer pathlength (ft), L_t ________
3. Calculated pathlength ratio ________
4. Preset pathlength ratio ________

B. Fault Indicator Lamps

5. BLOWER FAILURE ________
6. FILTER BLOCK ________
7. WINDOW ________

C. Instrument Zero And Span Checks

8. Opacity range switch initial position ________

9. Internal zero reading on control panel (mA) ________

10a. External zero reading on control panel (mA) ________

10b. External zero reading on chart recorder (% Op) ________

11. Control panel meter span value (mA) ________

12. Chart recorder span value (% Op) ________

D. Span Value Check

13. Span filter current value (mA) ________
14. Span filter opacity value (% Op) ________

E. Alignment Check

15. Images centered (on either side of "x") __________

F. Retroreflector Window Check

16. Time of cleaning __________

G. Transceiver Window Check

17. Time of cleaning __________

H. Install Audit Device

18. Time at end of waiting period __________

I. Insert Low Range Filter

19. Time at end of waiting period __________
20. Filter opacity (% Op) __________
21. Filter serial number __________

J. Insert Mid Range Filter

22. Time at end of waiting period __________
23. Filter opacity (% Op) __________
24. Filter serial number __________

K. Insert High Range Filter

25. Time at end of waiting period __________
26. Filter opacity (% Op) __________
27. Filter serial number __________

L. Monitor Response Repeatability

28-39. Time at end of waiting periods:

Low	Mid	High
28	29	30
31	32	33
34	35	36
37	38	39

M. Retrieve Retroreflector Window Check Data

40. Initial opacity reading (% Op) ____________

41. Final opacity reading (% Op) ____________

N. Retrieve Transceiver Window Check Data

42. Initial opacity reading (% Op) ____________

43. Final opacity reading (% Op) ____________

O. Retrieve Audit Device Installation Data

44. Opacity reading (% Op) ____________

P. Retrieve All Calibration Filter Data

45-59. Opacity readings (% Op):

Low	Mid	High
45	46	47
48	49	50
51	52	53
54	55	56
57	58	59

AUDIT ANALYSES

A. Stack Exit Correlation Error

60. Error (%):

$$= \left[\frac{(\text{Blank 4}) - (\text{Blank 3})}{(\text{Blank 3})}\right] \times 100$$

$$= \left[\frac{(\qquad\quad) - (\qquad\quad)}{(\qquad\quad)}\right] \times 100 = \underline{\qquad\qquad}$$

B. Meter Correction Factor

61. Panel meter factor:

$$= \frac{(\text{Blank 13})}{(\text{Blank 11})}$$

$$= \frac{(\qquad\quad)}{(\qquad\quad)} = \underline{\qquad\qquad}$$

C. Internal Span Error

62. Span error (% Op)

$$= (\text{Blank 12}) - (\text{Blank 14})$$

$$= (\qquad\quad) - (\qquad\quad) = \underline{\qquad\qquad}$$

D. Optical Surface Dust Accumulation

63. Transceiver Dust Accumulation (% Op):

$$= (\text{Blank 42}) - (\text{Blank 43})$$

$$= (\qquad\quad) - (\qquad\quad) = \underline{\qquad\qquad}$$

64. Retroreflector Dust Accumulation (% Op)

= (Blank 40) - (Blank 41)

= (   ) - (   ) = __________

65. Total Dust Accumulation (% Op)

= (Blank 63) - (Blank 64)

= (   ) - (   ) = __________

E. Pathlength Ratio Corrections on Audit Filters

66. Low range filter (% Op):

$= [1-(1-[(\text{Blank } 20)/100])^{(\text{Blank } 4)}] \times 100$

$= [1-(1-[(\qquad)/100])^{(\qquad)}] \times 100 =$ __________

67. Mid range filter (% Op):

$= [1-(1-[(\text{Blank } 23)/100])^{(\text{Blank } 4)}] \times 100$

$= [1-(1-[(\qquad)/100])^{(\qquad)}] \times 100 =$ __________

68. High range filter (% Op):

$= [1-(1-[(\text{Blank } 26)/100])^{(\text{Blank } 4)}] \times 100$

$= [1-(1-[(\qquad)/100])^{(\qquad)}] \times 100 =$ __________

F. Determine Mean Error for Low Range Audit Filter

69. Test #1 difference (% Op):

= (Blank 45)-(Blank 66)

= ( )-( ) = ____________

70. Test #2 difference (% Op):

= (Blank 48)-(Blank 66)

= ( )-( ) = ____________

71. Test #3 difference (% Op):

= (Blank 51)-(Blank 66)

= ( )-( ) = ____________

72. Test #4 difference (% Op):

= (Blank 54)-(Blank 66)

= ( )-( ) = ____________

73. Test #5 difference (% Op):

= (Blank 57)-(Blank 66)

= ( )-( ) = ____________

74. Mean error (% Op):

$$= \frac{(\text{Blank } 69)+(\text{Blank } 70)+(\text{Blank } 71)+(\text{Blank } 72)+(\text{Blank } 73)}{5}$$

$$= \frac{(\quad)+(\quad)+(\quad)+(\quad)+(\quad)}{5}$$

= ____________

G. Determine Mean Error for Mid Range Audit Filter

75. Test #1 difference (% Op):

= (Blank 46)-(Blank 67)

= (   )-(   ) = ________

76. Test #2 difference (% Op):

= (Blank 49)-(Blank 67)

= (   )-(   ) = ________

77. Test #3 difference (% Op):

= (Blank 52)-(Blank 67)

= (   )-(   ) = ________

78. Test #4 difference (% Op):

= (Blank 55)-(Blank 67)

= (   )-(   ) = ________

79. Test #5 difference (% Op):

= (Blank 58)-(Blank 67)

= (   )-(   ) = ________

80. Mean error (% Op):

$$= \frac{(\text{Blank } 75)+(\text{Blank } 76)+(\text{Blank } 77)+(\text{Blank } 78)+(\text{Blank } 79)}{5}$$

$$= \frac{(\quad\quad)+(\quad\quad)+(\quad\quad)+(\quad\quad)+(\quad\quad)}{5}$$

= ________

H. Determine Mean Error for High Range Audit Filter

81. Test #1 difference (% Op):

= (Blank 47)-(Blank 68)

= (   )-(   ) = ____________

82. Test #2 difference (% Op):

= (Blank 50)-(Blank 68)

= (   )-(   ) = ____________

83. Test #3 difference (% Op):

= (Blank 53)-(Blank 68)

= (   )-(   ) = ____________

84. Test #4 difference (% Op):

= (Blank 56)-(Blank 68)

= (   )-(   ) = ____________

85. Test #5 difference (% Op):

= (Blank 59)-(Blank 68)

= (   )-(   ) = ____________

86. Mean error (% Op):

$$= \frac{(\text{Blank } 81)+(\text{Blank } 82)+(\text{Blank } 83)+(\text{Blank } 84)+(\text{Blank } 85)}{5}$$

$$= \frac{(\quad\quad)+(\quad\quad)+(\quad\quad)+(\quad\quad)+(\quad\quad)}{5}$$

= ____________

I. Low Range Audit Filter Confidence Interval

87. $\Sigma|\text{Differences}|$:

$= |(\text{Blank } 69)| + |(\text{Blank } 70)| + |(\text{Blank } 71)| + |(\text{Blank } 72)| + |(\text{Blank } 73)|$

$= |(\qquad)| + |(\qquad)| + |(\qquad)| + |(\qquad)| + |(\qquad)|$

= ____________

88. $\Sigma(\text{Differences})^2$:

$= (\text{Blank } 69)^2 + (\text{Blank } 70)^2 + (\text{Blank } 71)^2 + (\text{Blank } 72)^2 + (\text{Blank } 73)^2$

$= (\qquad)^2 + (\qquad)^2 + (\qquad)^2 + (\qquad)^2 + (\qquad)^2$

= ____________

89. Confidence interval (% Op):

$= 0.2776 \times ([5 \times (\text{Blank } 88)] - [(\text{Blank } 87)^2])^{0.5}$

$= 0.2776 \times ([5 \times (\qquad)] - [(\qquad)^2])^{0.5} =$ ____________

J. Mid Range Audit Filter Confidence Interval

90. $\Sigma|\text{Differences}|$:

$= |(\text{Blank } 75)| + |(\text{Blank } 76)| + |(\text{Blank } 77)| + |(\text{Blank } 78)| + |(\text{Blank } 79)|$

$= |(\qquad)| + |(\qquad)| + |(\qquad)| + |(\qquad)| + |(\qquad)|$

= ____________

91. $\Sigma(\text{Differences})^2$:

$= (\text{Blank } 75)^2 + (\text{Blank } 76)^2 + (\text{Blank } 77)^2 + (\text{Blank } 78)^2 + (\text{Blank } 79)^2$

$= (\qquad)^2 + (\qquad)^2 + (\qquad)^2 + (\qquad)^2 + (\qquad)^2$

= ____________

92. Confidence interval (% Op):

$= 0.2776 \times ([5 \times (\text{Blank } 91)] - [(\text{Blank } 90)^2])^{0.5}$

$= 0.2776 \times ([5 \times (\qquad)] - [(\qquad)^2])^{0.5} =$ ____________

K. High Range Audit Filter Confidence Interval

93. $\Sigma\,|\text{Differences}|$:

$= |(\text{Blank } 81)|+|(\text{Blank } 82)|+|(\text{Blank } 83)|+|(\text{Blank } 84)|+|(\text{Blank } 85)|$

$= |(\qquad)|+|(\qquad)|+|(\qquad)|+|(\qquad)|+|(\qquad)|$

= ____________

94. $\Sigma(\text{Differences})^2$:

$= (\text{Blank } 81)^2+(\text{Blank } 82)^2+(\text{Blank } 83)^2+(\text{Blank } 84)^2+(\text{Blank } 85)^2$

$= (\qquad)^2+(\qquad)^2+(\qquad)^2+(\qquad)^2+(\qquad)^2$

= ____________

95. Confidence interval (% Op):

$= 0.2776 \times ([5\times(\text{Blank } 94)]-[(\text{Blank } 93)^2])^{0.5}$

$= 0.2776 \times ([5\times(\qquad)]-[(\qquad)^2])^{0.5} =$ ____________

L. Calibration Error

96. Low range error (% Op):

$= |(\text{Blank } 74)|+(\text{Blank } 89)$

$= |(\qquad)|+(\qquad) =$ ____________

97. Mid range error (% Op):

$= |(\text{Blank } 80)|+(\text{Blank } 92)$

$= |(\qquad)|+(\qquad) =$ ____________

98. High range error (% Op):

$= |(\text{Blank } 86)|+(\text{Blank } 95)$

$= |(\qquad)|+(\qquad) =$ ____________